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LABORATORY WORK
IN
ELECTRICAL ENGINEERING

(PRELIMINARY GRADE)

A SERIES OF LABORATORY EXPERIMENTS
FOR FIRST AND SECOND YEAR STUDENTS OF
ELECTRICAL ENGINEERING

BY

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PREFACE

Whilst conducting laboratory classes in Electrical Engineering the author has felt the need of a laboratory Manual suitable for that portion of the student's training usually called "Preliminary Grade," and preceding the more advanced work on Dynamos and Motors. To successfully carry on a large class without some such help is an impossibility, and the author hopes that this attempt to meet an undoubted want will prove of some service to teacher and student alike. The book contains, besides chapters on the more purely physical measurements of resistance, E.M.F., and Current, special chapters devoted to the Potentiometer and Calibration of electric measuring instruments.

The last chapter (Section M) consists of a series of purely technological experiments of a miscellaneous character. The author wishes to draw special attention to the fact that almost every experiment in this and the preceding chapter is followed by an example actually worked by his own students at Blackburn. These examples, besides serving to indicate the degree of accuracy expected from an average student, will also afford considerable help to a student carrying out the experiment. For obvious reasons these practical examples are not written up *quite* complete. An elementary knowledge only of algebra has been assumed.

The author would be glad at any time to receive and acknowledge suggestions for additional experiments for this chapter to be inserted as an appendix in a future edition.

Attention is also drawn to the standard specifications in Appendix I., and to the Tables, etc., in Appendix II., which contain all the figures of reference required in the book.

The author's heartiest thanks are due to his former teacher, Professor W. W. Haldane Gee, of Manchester, for many valuable suggestions and advice; and to Mr. Fred Farrar, Demonstrator at Blackburn, for his assistance in choosing the worked examples and for reading proofs.

JOHN ROBERTS, Jun.

Blackburn,
August 3, 1906.

CONTENTS

CHAPTER I

PAGE
THE GRAPHICAL REPRESENTATION OF EXPERIMENTAL RESULTS 1

CHAPTER II

SECTION O.—VERIFICATION OF OHM'S LAW

EXPT. NO.
O1. Constant Resistance Method 9
O2. Constant E.M.F. Method 11
O3. Constant Current Method 12

CHAPTER III

SECTION R.—MEASUREMENT OF RESISTANCE

R1. The Resistance of a Uniform Wire is Proportional to its Length . . 15
R2. Fall of Potential Method 16
R3. Proportional Deflection Method 18
R4. Substitution Method 19
R5. Wheatstone's Bridge Method 21
R6. Wheatstone's Bridge Method (Metre Bridge) 22
R7. Wheatstone's Bridge Method (P.O. Box) 24
R8. Wheatstone's Bridge Method (B.A. Wire Bridge) 26
R9. Direct Deflection Method of measuring Insulation Resistance . . . 28
R10. Silvertown Testing Set (Conductor Resistance) 30
R11. Silvertown Testing Set (Insulation Resistance) 32
R12. Internal Resistance of a Battery (Fall of Potential Method) . . . 33
R13. Resistance of Electrolytes (Kohlrausch Alternating-current Method) . 35

CHAPTER IV

SECTION E.—MEASUREMENT OF E.M.F.

E1. Equal Resistance Method 38
E2. Equal Deflection Method 39

EXPT. NO. PAGE
E3. Wiedemann's or Sum-and-Difference Method 41
E4. Lumsden's Method 43
E5. Clark-Poggendorff Method 44

CHAPTER V

SECTION C.—MEASUREMENT OF CURRENT

C1. Electrolysis of Copper-sulphate Method 47
C2. Electrolysis of Silver-nitrate Method 48
C3. Mixed Gas Voltameter Method 50
C4. Heating Effect Method 53

CHAPTER VI

SECTION P.—THE POTENTIOMETER.

Introduction 55
PI. (A) Measurement of E.M.F.'s 56
PI. (B) Measurement of High E.M.F.'s 57
P2. Measurement of Current 58
P3. Measurement of Resistance 60

CHAPTER VII

SECTION K.—CALIBRATION OF ELECTRICAL MEASURING INSTRUMENTS

Introduction 62
K1. Calibration of an Ammeter 63
K2. Calibration of a Voltmeter 67
K3. Calibration of a Wattmeter 73
K4. Test of an Electricity Meter 77
K5. Calibration of a Mirror Galvanometer 82
K6. Calibration of a Meter-bridge Wire 85

CHAPTER VIII

SECTION M.—MISCELLANEOUS EXPERIMENTS

M1. Variation of Resistance with Dimensions and Material 89
M2. Laws of Combination of Resistances 93
M3. Variation of Resistance with Temperature of Different Materials . . 95

EXPT. NO. PAGE
M4. Resistance Test on a Storage-cell (Potentiometer Method) . . . 98
M5. Variation of Resistance of an Incandescent Lamp with Voltage . . 101
M6. Complete Electrical Tests of Incandescent, Carbon, Tantalum, and Osmium Lamps 106
M7. Behaviour of an Arc Lamp on Continuous Circuit 111
M8. Photometric Tests on a Glow or Incandescent Lamp 116
M9. Photometric Test of an Arc Lamp 119
M10. The Distribution of Magnetic Field about a Straight Conductor . . 124
M11. Attractive Force of an Electro-magnet 128
M12. Influence of Air-gap on Attractive Force of an Electro-magnet . . 131
M13. Experiments on an Electro-magnet (Pull and Induction) . . . 133
M14. Experiments on an Electro-magnet (Pull and Area of Pole Face) . . 135
M15. Measurement of Magnetic Permeability (Thompson's Permeameter) . 138
M16. Hysteresis Tests (Ewing's Tester) 141
M17. Experiment on an Electric Bell 145
M18. Experiments on Fuses (Fusing-current and Diameter) 148
M19. Experiments on Fuses (Fusing-current and Diameter; Different Positions) 151
M20. Experiments on Fuses (Fusing-current and Length) 154
M21. Laws of Induction 157
M22. Measurement of Field, Armature, Brush, and Contact Resistances . . 159
M23. Temperature Measurements on a Machine 164
M24. The Shunt Dynamo (No-load Characteristic, Separate Excitation) . . 169
M25. The Shunt Dynamo (No-load Characteristic, Constant Excitation) . . 173
M26. The Shunt Motor (No-load Characteristic, Shunt Current and Speed) . 177
M27. Potential Curve of a Dynamo 180
M28. Magnetic Measurements on a Dynamo 184

APPENDIX I

CONTENTS
No. 1. Board of Trade Specification for the Manufacture of the Clark Standard Cell 189
„ 2. The Reichsanstalt Type of Cadmium Cell 194
„ 3. The Manufacture of a 1-ohm Coil 198

APPENDIX II

PHYSICAL TABLES

TABLE NO.
I. Useful Constants, etc. 200
II. Formulæ in Mensuration 201
III. Conversion Factors 201
IV. Specific Gravities and Specific Heats 203

TABLE. NO. PAGE
V. Specific Resistances and Temperature Coefficients of Pure Metals and Alloys 204
VI. Specific Resistance of Electrolytes in Ohms per c.c. 205
VII. Electro-chemical Equivalents in Grammes per Coulomb . . . 206
VIII. Properties of Primary Cells 207
IX. Relation between Practical and C.G.S. (absolute) Units . . . 208
X. Variation of E.M.F. of Clark Standard, and of Carhart-Clark Standard Cell, with Temperature 209
XI. Trigonometrical Ratios 210
XII. Logarithms and Antilogarithms 211
XIII. Trigonometrical Tables 215
XIV. Standard Wire-gauge Tables 216

LABORATORY WORK IN ELECTRICAL ENGINEERING

CHAPTER I

THE GRAPHICAL REPRESENTATION OF EXPERIMENTAL RESULTS

As a general rule, the results of an experiment are better recorded in the form of a curve than as columns of figures. The advantages of such a record are many, prominence being accorded to the fact that the nature of the variation of one quantity with the other can be more readily seen and understood than is possible with the results in tabular form. Inevitable errors of observation, etc., are also more easily seen and corrected, and the most probable corresponding intermediate values of the quantities (which generally are unobtainable from columns of experimental results) are at once obtained by inspection of the curve.

In a great many cases the "law" of variation of one quantity with the other can be expressed in mathematical form, and if such a law exists, its general form can be deduced by inspection of the shape of and the correct arithmetical values of the symbols it contains obtained by taking "points" on the curve. Only the very simplest laws can be obtained from results in tabular form.

The purpose of this chapter being to explain the deduction of the simple laws most frequently met with in practice from curves plotted to experimental results, the actual process of curve-plotting will be taken as understood. Sufficient it is to remark that one set of quantities, usually called X, are referred to one axis, the abscissa, or horizontal line; and the other set of quantities, called Y, to the ordinate, or vertical line. Points representing corresponding values of x and y are plotted on the paper, and an even curve drawn through them. The curve so obtained then represents the most probable corresponding values of, or the relation between, the two quantities x and y; and if the quantities plotted are experimental results, their accuracy or otherwise of measurement or observation can be judged by the proximity or otherwise of the points to the curve.

Experiment No. 1.—Plot the following curves :—

(i.) The relation between the speed (R.P.M.) and E.M.F. of a dynamo (volts), given the following values :—

Speed (R.P.M.)	300	536	696	842	985	1100	1210	1360
E.M.F. (volts)	25	45·5	58·6	71·0	83·2	93·0	102·2	116·0

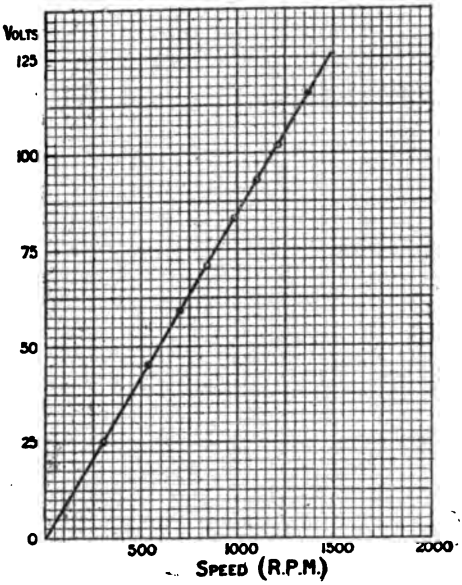


Fig. 1.

(ii.) The relation between the diameter (d) and area (A) of a circle, given the following values :—

d (cms.) . .	0·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0
A (sq. cms.)	0·1964	0·7854	1·767	3·142	4·909	7 069	9·621	12·57

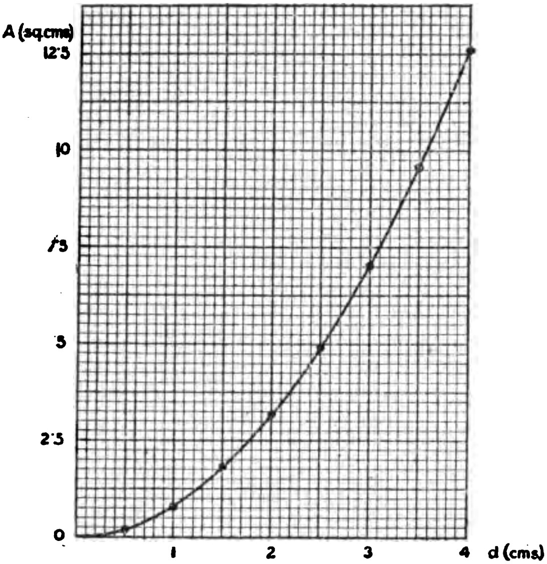


FIG. 2.

(iii.) The relation between an angle and its SINE.
(iv.) „ „ „ „ COSINE.
(v.) „ „ „ „ TANGENT.

All three curves to be plotted on the same base and for angles up to 90°. Values of sin, cos, and tan are given in the tables at the end of the book.

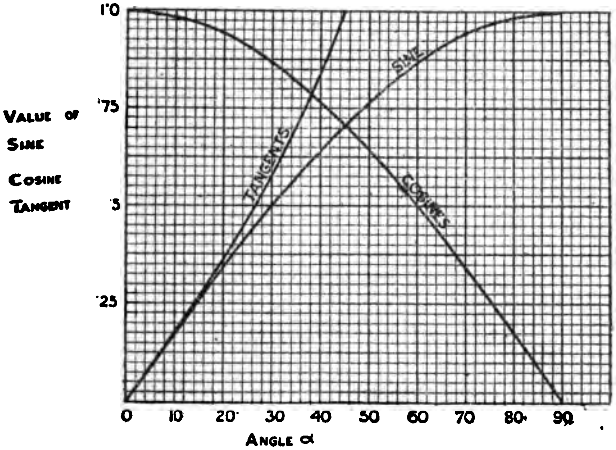


FIG. 3.

To find the Equation or Law of a Simple Curve.—The general law of the type of curve shown in curve (i) is

$$y = mx + C$$

where y and x are corresponding values of the two quantities, and m and C are constants. Such "straight-line" curves are called "Curves of the First Degree."

The general law of the type of curve shown in curve (ii) is

$$y = mx^n + C$$

where m, C, and n are constants. Such a curve is a "Curve of the Second Degree."

To find the Law of a Curve of the First Degree.—A test on a large steam generator gave the following results:—

Total steam, lbs. .	14,600	12,500	10,400	8,315	4,020	1,800
Output, kilo-watts .	600	500	400	300	100	0

When plotted on squared paper, they are found to give a straight-line curve, as in Fig. 4.

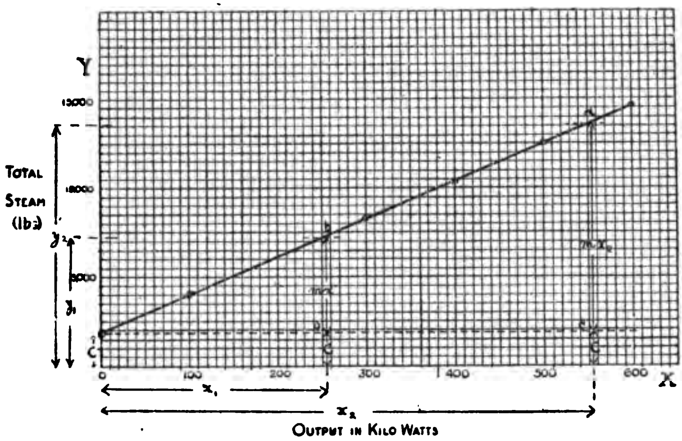


Fig. 4.

The general law of this curve is—

$$y = mx + C$$

from which it is evident that when $x = 0$ $y = C$, or C is the reading where the curve cuts Oy, the axis of y, as shown in the figure. Draw a line at a distance C from Ox as shown, then from the curve it is evident all ordinates, such as ab, cd, etc., measured above this line to the curve increase in direct proportion to the corresponding values of x, x_1, x_2, etc., or that for values of y measured above the link line ac—

$$y = mx$$

where m is a constant.

Clearly for values y measured from Ox

$$y = mx + C$$

which proves the general law stated above.

To find the law, choose any two points, b and d say, and take the values of x_1 y_1 and x_2 y_2, and insert in the general equation, thus—

$$7170 = m x 250 + c$$
$$13{,}540 = m x 550 + c$$

By subtraction—

$$6370 = 300\, m$$
$$\therefore m = 21{\cdot}23$$

By substitution—

$$7170 = 21{\cdot}23\, x . 250 + c$$
$$\therefore c = 1860$$

So that the law of this curve is—

Steam (lbs.) = 21·23 x Kilo Watts + 1860.

To find the Law of a Curve of the Second Degree.—The following figures were obtained in a test on an electric motor:—

Armature voltage	150	130	110	90	70	50
Watts consumed	706	637	577	523	480	445

The curve plotted to these figures is the thick black one in Fig. 5 below—

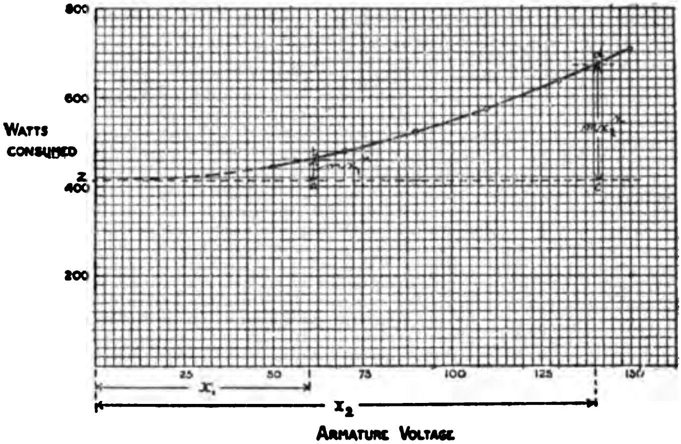


FIG. 5.

It is thought from the appearance of the curve that it follows the general law of the Second Degree curves, viz.—

$$y = mx^n + C.$$

Obviously, when $x = 0$ $y = C$, or C is given by the ordinate *oz* in the figure, the curve being estimated to continue along the link line shown. This gives C equal to about 412. As before, draw the line *zac* equal to C; then it is clear that if the curve *does* follow the law—

$$y = mx^n + C,$$

the ordinates *ab*, *cd*, etc., represent the quantities mx_1^n, mx_2^n, for values x_1, x_2, etc., of x.

The expression $y = mx^n + C$ may be written

$$y - C = mx^n$$

or

$$\log (y - C) = \log m + n \log x.$$

Since *m* and *n* are constants, it follows that a curve plotted to the values log (y − C) and log x will be a straight line. Hence this provides a means of ascertaining whether the curve follows the law stated. Values of $(y - C)$ are given in the curve by the ordinates *ab*, *cd*, etc., for the values x_1, x_2, etc., of x, the value of C being 412. Taking points, the following values are obtained from the curve:—

Volts	40	60	80	100	120	140
Watts	433	460	497	547	605	673
(Watts − 412) .	21	48	85	135	193	261
log volts . . .	1·6021	1·7782	1·9031	2·000	2·0792	2·1461
log (Watts − 412)	1·3222	1·6812	1·9294	2·1303	2·2856	2·4166

Plotting the last two columns give the following curve:—

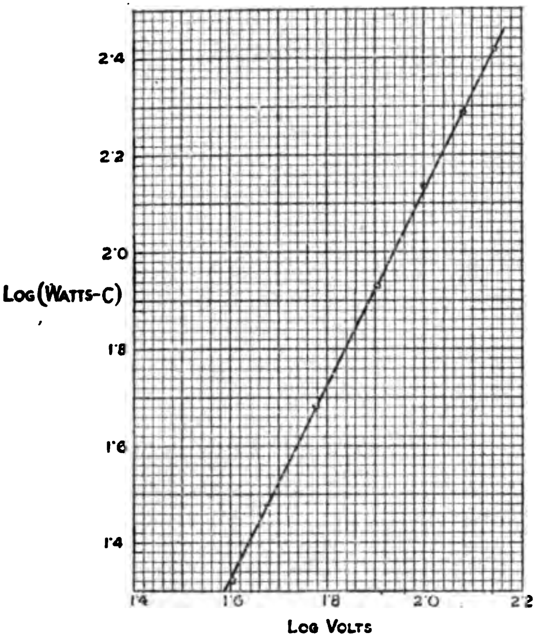


Fig. 6.

It is seen that the points lie very well on a straight line, indicating that the curve is of the Second Degree. If the points were found *not* to lie on a straight line, then the curve follows some law (if at all) which is beyond the scope of this short chapter. However, it can safely be said that the great majority of the more common laws met with in practice are those of the First and Second Degree.

To find the Law.—Having ascertained that the curve follows the second law, and knowing the value of C (412), the next step is to find the values of *m* and *n*. We have seen that the law may be stated—

$$\log(\text{Watts} - C) = \log m + n \log \text{volts}$$

Inserting the values for any two points on the curve, say *d* and *b*, gives the two equations—

$$\left.\begin{array}{l}\log(673 - 412) = \log m + n \log 140 \\ \log(460 - 412) = \log m + n \log 60\end{array}\right\}$$

From the tables of logs—

$$\begin{array}{rl} & 2{\cdot}4166 = \log m + n\, 2{\cdot}1461 \\ & 1{\cdot}6812 = \log m + n\, 1{\cdot}7782 \\ \hline \text{By subtraction—} & 0{\cdot}7344 = 0{\cdot}3679n \\ & \therefore n = 2^{*} \end{array}$$

To find the value of *m*, substitute for *n* in any of the equations given above, viz.—

$$\begin{aligned} \log(673 - 412) &= \log m + 2 \log 140 \\ \therefore 2{\cdot}4166 &= \log m + 2 \times 2{\cdot}1461 \\ \therefore \log m &= -1{\cdot}8756 \text{ or } \bar{2}{\cdot}1244 \\ \text{Anti-log } \bar{2}{\cdot}1244 &= 0{\cdot}01331 \\ \therefore m &= 0{\cdot}01331 \text{ (say } 0{\cdot}0133) \end{aligned}$$

Hence the law of the curve is—

$$\textbf{WATTS} = 0{\cdot}0133\ \textbf{VOLT}^2 + 412$$

Experiment.—Find the laws of curves (i) and (ii) in this chapter.

---

* 0·7354 ÷ by 0·3679 gives 1·9986; but as the values inserted in the equations are estimated from the curve, the value 2 is just as likely to be correct as 1·9986, and is much more convenient to state.

CHAPTER II

VERIFICATION OF OHM'S LAW

Experiment No. O1.—Verification of Ohm's Law (Constant Resistance Method).

Introduction.—Ohm's Law states that the current flowing in a circuit is equal to the ratio of the applied E.M.F. to the total resistance of that circuit.

If C = current flowing,
E = E.M.F. applied,
R = total resistance of the circuit,

$$\text{Then } C = \frac{E}{R}$$

The object of this experiment is to show that if the total resistance R of the circuit is unaltered, the ratio of E.M.F. to current, or $\frac{E}{C}$, is also constant.

Diagram of Connections.—

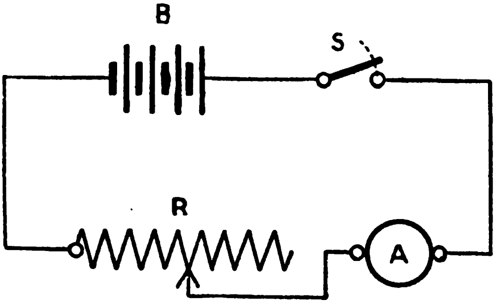


FIG. 7.

Apparatus required.—

B = battery of several similar cells of equal and constant E.M.F. and small internal resistance.
R = adjustable resistance.

A = low-reading ammeter (milli-ammeter), or a galvanometer of which the relation between the current passing through it and the deflection produced, is known, *i.e.* a tangent or a sine galvanometer.

S = switch or key.

Method.—(1) With the maximum number of cells in series, and with S closed, adjust R so as to obtain a conveniently large deflection on A. (NOTE.—The value of R should be large compared with the internal resistance of the battery B, which may be taken as a maximum of three ohms per cell for Leclanché cells.) Note the current indicated on A, and N the number of cells.

(2) Remove one cell, leaving R unaltered. Note the new value of C and the number of cells.

(3) Continue to remove one cell at a time, noting in each case the number in circuit and the indication on A.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
No. of cells, N.	Indications of A = C.	Ratio $\frac{N}{C}$	Remarks.

If a galvanometer be used for A, tabulate your results thus—

I.	II.	III.	IV.	V.
No. of cells, N.	Deflection on galvanometer δ.	Tan δ or sine δ.	Ratio $\frac{N}{\tan\delta \text{ or } \sin\delta}$.	Remarks.

Plot a curve showing the relation between N and C, taking values of N for abscissæ, and values of C for ordinates. Show from the curve so plotted that the ratio $\frac{N}{C}$ is constant.

If a galvanometer has been used for A, substitute tan δ or sine δ for C in above, and proceed as indicated.

Experiment No. O2.—Verification of Ohm's Law (Constant E.M.F. Method).

Introduction.—Ohm's Law states that if in a circuit the applied E.M.F. is kept constant, then the product of the total resistance of, and the current flowing in the circuit is constant also.

If C = current flowing,
E = E.M.F. applied,
R = total resistance of the circuit,

$$\text{Then } E = C \cdot R$$

The object of this experiment is to show that by keeping E constant, the product of C and R is also constant.

Diagram of Connections.—

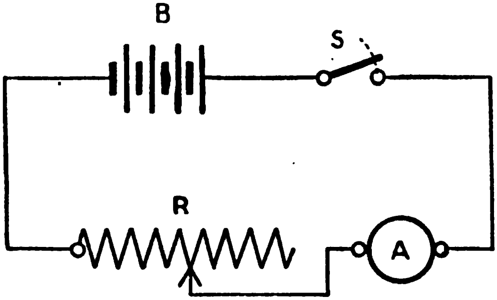


FIG. 8.

Apparatus required.—
B = battery of several cells of constant E.M.F. and low internal resistance compared with R.
R = known adjustable resistance.
A = low-reading ammeter.
S = switch or key.

Method.—(1) Place the maximum R in circuit and close S. Note the value of R and the current indicated on A.

(2) Decrease R by an amount sufficient to alter the indication on A by a suitable step. Note the new values of R and C.

(3) Repeat operation (2) until a suitable range of values of R and C (say of about 10 readings) has been obtained.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Resistance, R.	Indications on A – C.	Values of $\frac{1}{C}$	Values of C × R.	Remarks.

Since E is constant, R varies as $\frac{1}{C}$, $\left(R = \frac{E}{C}\right)$. Plot a curve having values of R for ordinates, and of $\frac{1}{C}$ for obscissæ, and show how the curve obtained proves the law stated above, viz. C × R is constant.

If a galvanometer be used for A, proceed as explained in the previous experiment. Also, if the internal resistances of the battery B and galvanometer A are not small compared with R, their resistance will have to be added in each case to that of R, and the sum, being the total circuit resistance, entered in column I of the table of results.

Experiment No. O3.—Verification of Ohm's Law (Constant Current Method).

Introduction.—Ohm's Law states that if in a circuit the current is unaltered, then the ratio of the applied E.M.F. to the total resistance of the circuit is also constant.

If C = current flowing,
E = E.M.F. applied,
R = total resistance of the circuit,

$$\text{Then } C = \frac{E}{R}$$

The object of this experiment is to show that if C is kept constant, the ratio $\frac{E}{R}$ is also constant.

Diagram of Connections.—

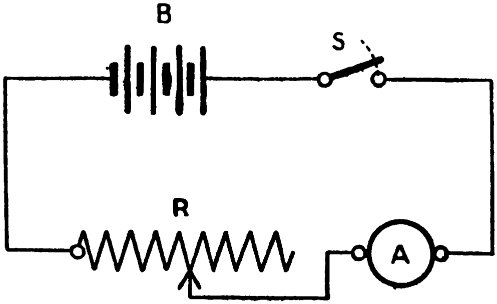


FIG. 9.

Apparatus required.—

B = battery of several cells of equal and constant E.M.F. and low internal resistance compared with R.

R = adjustable known resistance.

A = low-reading ammeter.

S = switch or key.

Method.—(1) Using all the cells in series, adjust R to obtain a convenient C indicated on A. Note R and N the number of cells.

(2) Remove one cell and adjust R so as to obtain the same C as formally indicated on A. Note R and N.

(3) Repeat (2), noting for each value of N the corresponding value of R to obtain the same C indicated on A.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Resistance, R.	Indications on A – C.	No. of cells, N.	Ratio $\frac{N}{R}$	Remarks.

Since N represents the E.M.F. of the battery, the ratio $\frac{N}{R}$ should be constant. Plot a curve having values of N for ordinates and of

R for abscissæ, and show how the curve obtained proves the law stated above, viz. $\frac{E}{R}$ is constant.

If a galvanometer be used for A, and if the sum of its resistance and that of the cells is not small compared with R, the same remarks apply here as in the last experiment.

CHAPTER III

THE MEASUREMENT OF RESISTANCE

Experiment No. R1.—The Resistance of a Uniform Wire is Proportional to its Length.

Introduction.—The resistance per unit length of a uniform wire is the same throughout its length. The experiment is to prove that the resistance between two points is proportional to the length of wire between them. The method employed is a direct application of Ohm's Law (viz. that with a steady current flowing along a wire, the resistance between two points is directly proportional to the potential difference between them); and consists in directly measuring the drop of potential over various lengths of a uniform wire through which a steady current is flowing.

Diagram of Connections.—

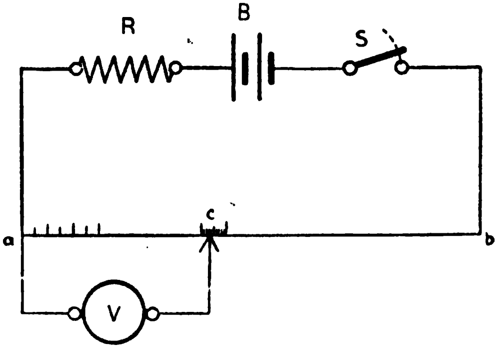


FIG. 10.

Apparatus required.—

B = battery.
R = resistance (say 10 ohms).
V = high-resistance low-reading voltmeter.
S = switch or key.
ab = uniform wire.

Method.—(1) Place the movable contact point *c* of the Voltmeter a short distance from the end *a* of the uniform wire *ab*. Close S, measure the distance D of point of contact *c* from *a*, and note the reading on V.

(2) Gradually increase D by moving the point *c* towards *b*, noting in each case the corresponding values of D and V.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
Readings on V.	Distance, D.	Ratio $\frac{V}{D}$ representing resistance per unit length of wire.	Remarks.

Plot a curve showing the relation between V and D, taking values of V as ordinates, and of D as abscissæ, and show how the curve obtained proves the law of the variation of resistance with length of a uniform wire. If a high-resistance galvanometer be used in place of V, the currents corresponding to its deflections will need to be obtained, viz. for a tangent galvanometer tan δ, for a sine galvanometer sine δ, etc.

Since these values represent the potential difference at the terminals of the galvanometer they will be substituted for column III. above, and a column IV. giving the ratio tan δ or sine δ, etc., given to correspond with column III. above, and the curve plotted accordingly.

Experiment No. R2.—Fall of Potential Method.

Introduction.—The relative resistances of two portions of the same circuit carrying a current are directly proportional to the fall of potential along them. If, then, in a simple series circuit the falls of potential in two resistances, one of which is known, are measured, the other can be calculated.

Diagram of Connections.—

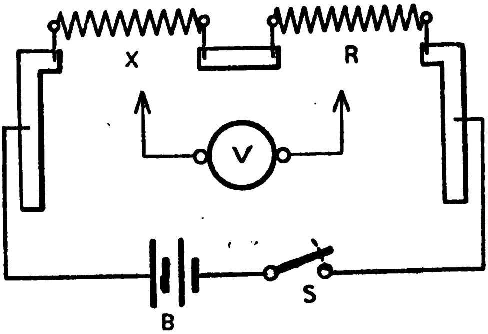


FIG. 11.

Apparatus required.—

X = unknown resistance to be measured.
R = known resistance.
B = battery.
V = high resistance voltmeter.
S = switch or key.

Method.—(1) Close S (having previously arranged the value of R, or the number of cells in B so as to allow a small current C only to flow).

(2) Measure the fall of potential V_R along R.

(3) " " " V_X " X.

(4) As this method is dependent on C remaining constant over (2) and (3), check its constancy by again measuring V_R.

(5) Repeat the experiment for a larger and for a smaller number of cells, noting the corresponding values of V_X and V_R.

Then by Ohm's law—

$$V_X = C.X. \text{ and } V_R = C.R$$

C being the same throughout the circuit, we get—

$$X : R = V_X : V_R$$

$$\therefore X = \frac{V_X}{V_R} . R$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Description of unknown resistance, X.	Value of R.	V_X	V_R	$X = \frac{V_X}{V_R}.R$	Remarks.

If a high-resistance galvanometer of known law be used in place of V, the method given in the previous experiment should be followed.

Experiment No. R3.—Proportional Deflection Method.

Introduction.—This method of measuring resistance depends upon the fact that the current flowing in a circuit is inversely proportional to the resistance of that circuit. If the resistance of the external circuit is small compared with that to be measured, and also with the known resistance employed, and if both circuits are supplied with the same E.M.F., then the values of the known and unknown resistances will be inversely proportional to the relative currents through each.

Diagram of Connections.—

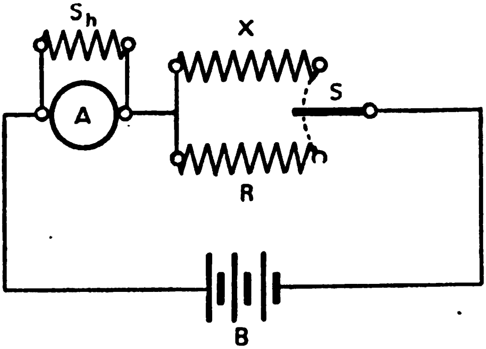


Fig. 12.

Apparatus required.—

B = battery.
X = unknown resistance to be measured.
R = known resistance.
A = low-reading ammeter.
S = two-way switch.
Sh = shunt on ammeter A (if necessary).

Method.—(1) Place S on X, and arrange for a convenient deflection on A by altering the number of cells at B, or by arranging a suitable shunt across A. Note the deflection C_X.

(2) Switch S on R, leaving the rest of the circuit unaltered, and note the new deflection C_R.

(3) Repeat (1) and (2) for different values of C_X and C_R.

Then, as explained above—

$$C_R : C_X :: X : R$$

$$\text{and } \therefore X = \frac{C_R}{C_X} \cdot R$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Description of unknown resistance, X.	Value of R.	Deflection, C_X.	Deflection, C_R.	$X = \frac{C_R}{C_X} . R.$	Remarks.

If instead of A a galvanometer of known law be used, then the values of C_X and C_R above will need to be found from their respective deflections δ_X and δ_R, and the value of X calculated as above. For example, with a tangent galvanometer, C_X is proportional to tan δ_X, and C_R is proportional to tan δ_R.

The relation then takes the form—

$$\tan \delta_R : \tan \delta_X :: X : R$$

$$\text{and } \therefore X = \frac{\tan \delta_R}{\tan \delta_X} . R$$

Experiment No. R4.—Substitution Method.

Introduction.—If an E.M.F. E be applied to a simple circuit composed of resistances X, B, and A in series, then a certain current C (say) will flow through it whose value is given by Ohm's law—

$$\text{viz. } C = \frac{E}{X + B + A}$$

If for the portion X of the circuit there be substituted a resistance R, such that by doing so C remains unaltered, then the total resistance is the same as formerly, *i.e.*

$$C = \frac{E}{X + B + A} = \frac{E}{R + B + A}$$

$$\therefore X + B + A = R + B + A$$

$$\therefore X = R$$

The object of this experiment is to find the value of an unknown resistance X by substituting for it such a value of known resistance R as to leave C unaltered. Then X = R.

Diagram of Connections.—

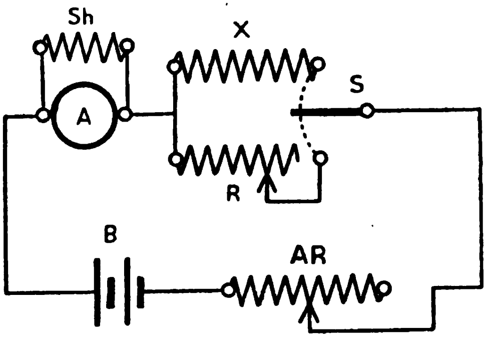


FIG. 13.

Apparatus required.—

X = unknown resistance to be measured.
R = known adjustable resistances.
AR = adjustable resistance.
B = battery.
A = ammeter (low-reading) or other current indicating instrument.
S = two-way switch.
Sh = shunt on ammeter A (if necessary).

Method.—(1) Place S on X, and adjust AR to obtain a conveniently small C indicated on A. Note C.

(2) Leave AR unaltered, and place S on R. Adjust R so that A indicates the same current C. Note R and C.

(3) Repeat (1) and (2) for various values of C obtained by adjusting AR, noting the values of C and the corresponding values of R.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Description of unknown resistance, X.	Indication on ammeter = C.	Value of R.	Value of X (= R).	Remarks.

NOTE.—As the accuracy of this method depends on the E.M.F. of

B remaining constant for two corresponding readings, it should be checked each time by again switching S on to X, when the same reading C should be obtained.

Experiment No. R5.—Wheatstone's Bridge Method (Preliminary Experiment).

Introduction.—If an E.M.F. be applied to the ends of a parallel circuit of, say, two conductors, the total fall of potential will be the same in both; and, since the extremities of both are connected together, the fall of potential in both will be between the same *absolute* potentials. Hence for any point on the one conductor there will be a corresponding point (and *only one* point) on the other conductor at the same potential. Clearly, then, the fall of potential from the extremity of one conductor to the point considered in it is equal to the fall of potential along the other conductor from the same extremity to the point corresponding to that in the first conductor. Similarly the fall of potential along the remainders of the conductors will also be equal. Further deductions from this will be made clearer from the diagram of connections.

Diagram of Connections.—

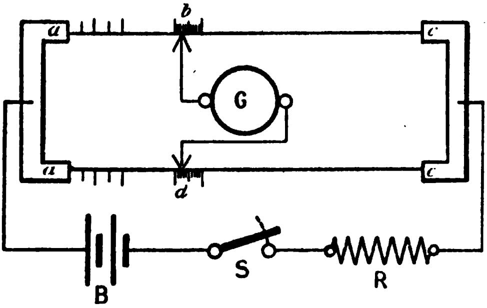


FIG. 14.

Apparatus required.—

abc and *adc* = two uniform wires attached to suitable contact blocks *aa* and *cc*.
B = battery.
S = switch or key.
G = galvanometer.
R = resistance.

Let *b* be the point considered in the first wire *abc*, then there is some point, *d*, in the second wire *adc* at the same potential as *b*. This can be found by choosing point *b* on the first wire, and moving the other wire of the galvanometer along *ac* until there is no deflection on G; then that point so found, *d*, is at the same potential as *b* (there being no flow of current between points of equal potential). The fall of potential along *ab* is therefore equal to that along *ad*, and that along *bc* to that along *dc*. But, from a previous experiment, the fall of potential in a uniform wire is directly proportional to its length, and therefore—

$$\frac{\text{length } ab}{\text{length } ad} = \frac{\text{length } bc}{\text{length } dc}$$

$$\text{also } \frac{\text{length } ab}{\text{length } bc} = \frac{\text{length } ad}{\text{length } dc}$$

In this experiment it is required to verify these laws.

Method.—(1) Close S. Choose a point, *b*, on wire *abc*, and with the other galvanometer wire find the point *d* in *adc*, where there is no deflection on G. Then *d* is at the same potential as *b*.

(2) Measure *ab*, *bc*, *ad*, and *dc*, and note them.

(3) Choose other points, *b*, and repeat (2), noting in each case as accurately as possible the lengths of wire *ab*, *bc*, *ad*, and *dc*.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
ab	*bc*	*ad*	*dc*	Ratio $\frac{ab}{ad}$	Ratio $\frac{bc}{dc}$	Ratio $\frac{ab}{bc}$	Ratio $\frac{ad}{dc}$	Remarks.

Experiment No. R6.—Wheatstone's Bridge Method (Metre Form of Bridge).

Introduction.—Read the explanation in the Preliminary Experiment in this method. Referring to the Diagram of Connections there, the potential drop in a conductor is proportional to the resistance between the two points considered, and therefore—

$$\frac{\text{resistance of } ab}{\text{resistance of } ad} = \frac{\text{resistance of } bc}{\text{resistance of } dc}$$

$$\text{also } \frac{\text{resistance of } ab}{\text{resistance of } bc} = \frac{\text{resistance of } ad}{\text{resistance of } dc}$$

The following diagram represents the most usual form of Wheatstone's Bridge for laboratory use.

Diagram of Connections.—

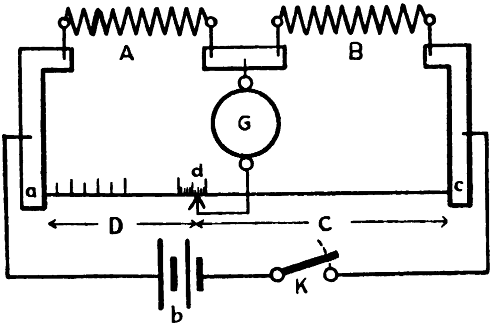


FIG. 15.

Apparatus required.—

A = known resistance.
B = resistance to be measured.
ac = long uniform wire with graduated scale.
b = battery.
K = battery key or switch.

Referring to the relation given above—

If D = length *ad*
C = length *dc*
A = resistance of A
B = resistance of B

Then $A = \frac{B.D}{C}$ $B = \frac{A.C}{D}$ $C = \frac{B.D}{A}$ and $D = \frac{A.C}{B}$

Thus, knowing any three, the fourth can be calculated. In the above diagram, B is the position of the unknown resistance, and its value is found by the expression given above, viz.—

$$B = \frac{A.C}{D}$$

Method.—(1) Close K and then *d*. Find the point *d* for no deflection on the galvanometer G. Open *d* and then K, noting the values of D and C in cms., and the resistance A in ohms.

(2) Substitute other known resistances for A, and repeat operation (1).

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
A (ohms).	C (cms.).	D (cms.).	$B = \frac{AC}{D}$ (ohms).	Remarks.

Experiment No. R7.—Wheatstone's Bridge Method ("Post Office Box" Form of Bridge).

Introduction.—The diagram of connections given in the previous experiment is usually given by a diamond-shaped figure, which, for purposes of explanation, will be given here. The following *diagram of connections* corresponds exactly to that given in the previous experiment.

Diagram of Connections.—

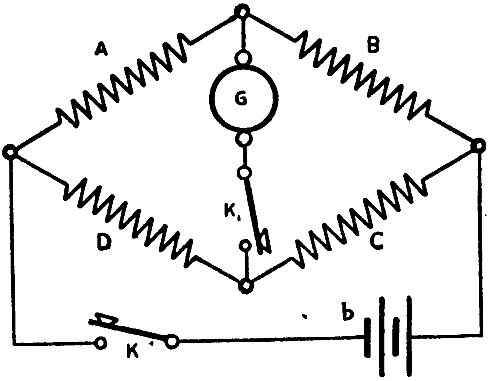


Fig. 16a.

The metre form of bridge is neither portable nor convenient in use. To meet these desirata a portable form of bridge, called the "Post office box," is used. A complete description of it may be found in any of the text-books on this subject. The diagram of connections given below corresponds exactly to that given above, and will be easily understood by reference to it and to the actual box.

Diagram of Connections.—

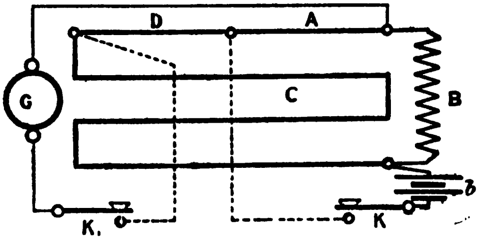


Fig. 16b.

Apparatus required.—

A, D, C, K, K_1 = Post office box.
B = unknown resistance to be measured.
G = galvanometer.
b = battery.

In the box the portions A and D are called "proportional arms," and the portion C the "adjustable arm."

Method.—(1) Take out plugs 10 and 10 in A and D, and the plug marked INF in C. Close K and sharply tap K_1; the galvanometer will be deflected, and this direction indicates throughout the experiment that C is too high.

(2) Replace INF plug, and adjust C so that on closing K and tapping K_1 an approximate balance is attained.

(3) Obtain an accurate balance by closing K_1 and adjusting C to get no deflection. If the value of C for an accurate balance cannot be adjusted it should be taken slightly greater, and then slightly less, and the true value of B calculated from the deflections on G by simple proportion.

Note A, D, and C.

(4) Repeat for A and D = 100, and then = 1000. Note A, D, and C in each case.

(5) Repeat for various ratios of A to D, noting in each case the values of A, D, and C.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Resistance tested, B.	Resistances.			$B = \frac{A}{D} C.$	Remarks.
	A	D	C		

Experiment No. R8.—Wheatstone's Bridge Method (B. A. Wire Bridge).

Introduction.—This form of Bridge is similar in principle and manipulation to that in Experiment No. 7, the difference being that a large portion of the wires marked D and C in the diagram of connections for that experiment are replaced by coils having corresponding resistances to the portions they replace, the remaining portions of D and C being made into a longer length, thereby making it possible to obtain more exact results.

The following diagram is lettered to correspond to those given in the previous experiments.

Diagram of Connections.—

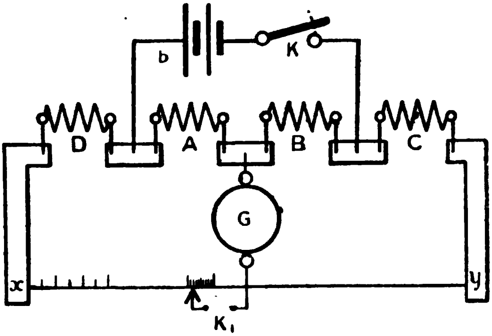


Fig. 17.

Apparatus required.—

A = known resistance.
B = resistance to be measured.

D and C = known resistances replacing portions of former wires, D and C.
xy = uniform wire—the remaining portions of former wires, D and C.
G = galvanometer.
b = battery.
K_1 and K = galvo and battery keys.

From the above diagram it is seen that when a balance is obtained—

$$A : B = D + \text{resistance of length } d \text{ of wire } xy : C + \text{resistance of length } c \text{ of wire } xy \quad . \quad . \quad . \quad . \quad (1)$$

It will therefore be necessary to know the resistance per unit length of the wire xy. If this is not known, it should be found by making $d = 0$, and $A = B$. Then, by placing a known resistance at D, and adjusting another known adjustable resistance at C until a balance is obtained,

$$D = C + \text{resistance of } xy,$$

from which the resistance per unit length, say ρ, can be calculated.

Hence from (1) above—

$$A : B = D + d\rho : C + c\rho$$
$$\therefore B = \frac{A(C + c\rho)}{D + d\rho}$$

The method gives more accurate results when A and B, and C and D are nearly equal, so that d is nearly equal to c.

Method.—(1) Close K and then K_1, and obtain a balance as before. Note A, C, D, d, and c.

(2) Alter the values of A, D, and C and again balance, noting A, C, D, d, and c in each case.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Resistances.				c	d	$c\rho$	$d\rho$	$B = \frac{A(C + c\rho)}{D + d\rho}$	**Remarks.**
ρ	A	C	D						

Experiment No. R9.—Direct Deflection Method of measuring Insulation Resistance.

Introduction.—This method of measuring insulation resistance is the one most frequently employed in practice in the measurement of the insulation resistances of electric light cables, field-magnet coils, and of various other apparatus, in which an easy and convenient method is desirable. The principle of the method consists in subjecting the insulation to an electrical pressure somewhat higher than that to which it is normally exposed, and of measuring the small current passing through it due to this pressure. By comparing this current with that caused to pass through a known high resistance due to the same voltage applied, the insulation resistance of the apparatus tested is obtainable.

Diagram of Connections.—

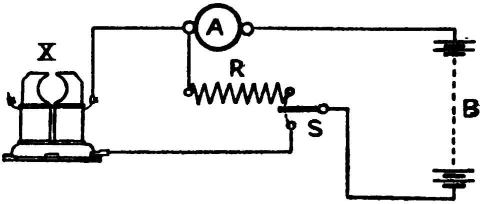


FIG. 18.

Apparatus required.—

A = low-reading ammeter or galvanometer of known law, with
R = known high resistance (about one megohm).
X = apparatus to be tested.
B = source of high E.M.F. (200 to 500 volts, according to the voltage to which the apparatus is normally subjected).
S = two-way switch.

Method.—(1) Connect up as in the diagram above, taking care to connect one wire to one or both ends of the field coil, so as to stand clear of any other apparatus, and the other wire to a suitable connection on the frame of the machine. Since this latter wire is practically earthed, the former connecting wire must be slung clear of all other apparatus between A and the field-coil wire, and should preferably be well insulated from A to B. The two-way switch S and the known high resistance R should also be very well insulated.

(2) Place a shunt across the terminals of A, and tap S on R for a fraction of a second only. If the deflection on A is too large or too small, alter the shunt to give a convenient deflection when S is switched on R. Note the deflection on A.

(3) With A unaltered switch S on X, and note the reading on A.

(4) Decrease the testing E.M.F. of B and repeat (2) and (3), noting in each case the approximate testing E.M.F. and the deflections on A.

Let C_R = readings on A when S is on R.
C_X = „ A „ „ X.

Then if the resistance of the remainder of the circuit is small compared with R or X;

$$X = R \cdot \frac{C_R}{C_X}$$

In observation (2) the same shunt on A may not give a convenient deflection.

In such a case the shunt may be altered in value so as to give a larger or a smaller reading, as may be required. If a different shunt is used, the calculation of X will be as follows:—

Let S_X = shunting value of shunt with X (10, 100, 1000, etc.).
S_R = „ „ „ R (10, 100, 1000, etc.).
δ_X = deflection on A with X and S_X.
δ_R = „ A „ R „ S_R.

Then if the current through A is represented by its deflection—

$$X \cdot S_X \cdot \delta_X = R \cdot S_R \cdot \delta_R$$
$$\therefore X = \frac{R \cdot S_R \cdot \delta_R}{S_X \cdot \delta_X}$$

If a tangent galvanometer be used for A, the values of tangent δ_R and tangent δ_X will have to be substituted for δ_R and δ_X in the above equation.

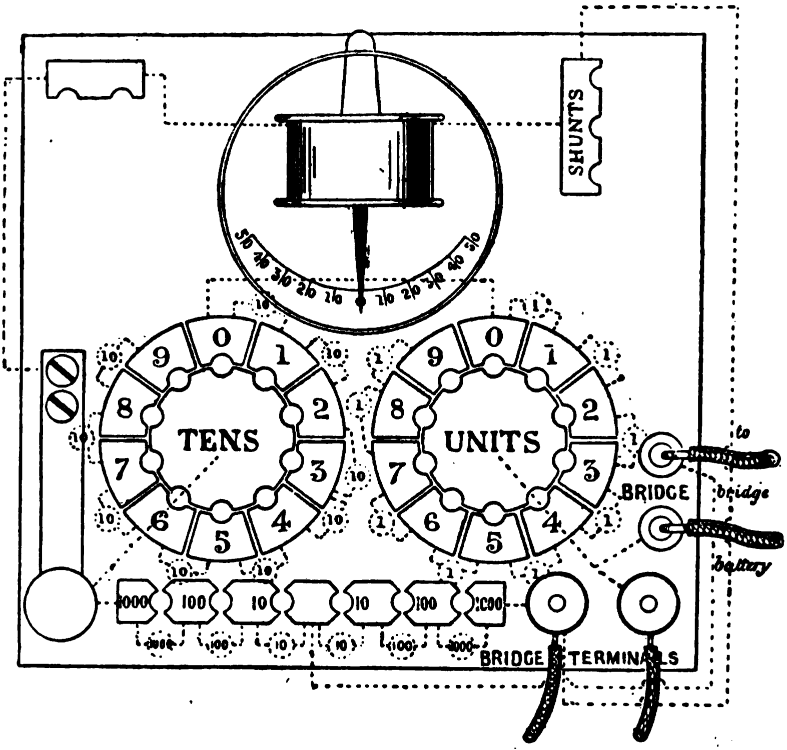
Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VI.	VIII.
Apparatus tested.	R (ohms)	S_R	δ_R	S_X	δ_X	$X = \frac{R \cdot S_R \cdot \delta_R \text{ (ohms)}}{S_X \cdot \delta_X}$	Remarks.

Experiment No. R10.—Silvertown Testing Set (Conductor Resistance).

Introduction.—This method is on the same principle as the Wheatstone bridge, the only difference being one of construction. The apparatus contains, besides the bridge, its own galvanometer with a controlling magnet to vary its sensitiveness. The connections will be apparent by reference to the actual box and the following diagram, which shows only those portions of the box used for measuring conductor resistance.

Diagram of Connections.—



To the ends of the Conductor.

Fig. 19.

Apparatus required.—The apparatus consists of (1) the adjustable resistance, consisting of two circular plug commutators, each having nine equal resistances. That marked TENS contains nine 10 watts resistances, whilst that marked UNITS contains nine 1 ohm resistances. Both these commutators are in series, and the resistances of this variable arm are indicated on the two commutators by the positions of the plugs.

For example, plug in, say, hole marked 4 in the ten-ohm dial, and the other plug in, say, hole marked 7 in units dial, gives a total resistance of $(4 \times 10) + (7 \times 1) = 47$ ohms. It will be evident from the diagram that placing both plugs in the holes marked 0 gives zero resistance, and that if no plug is inserted in either or both dials, the resistance is infinity.

(2) The proportional arms containing resistances of 10, 100, and 1000 (only one of which is to be unplugged on either side during a test) are similar to those on the post office box.

(3) The galvanometer (shown unshunted in the diagram) and its key. The battery, usually consisting of three Leclanché cells, is connected by means of plugs, which serve the purpose of a switch, to the terminals marked BRIDGE. The resistance to be tested is connected to the two terminals marked BRIDGE TERMINALS.

Method.—(1) Adjust the galvanometer pointer to zero by means of the controlling magnet on the left-hand side of the box.

(2) Plug holes 10, 10 in the proportional arms; connect up the battery and obtain an approximate balance by adjusting the resistance plugs and sharply tapping the galvanometer key. If the resistance to be measured is less than one ohm or more than 100 ohms, the left hand or the right hand proportional arm will have to be increased, as the case may be.

(3) The above result will be accurate to 1 per cent. only as a maximum. Further accuracy may be obtained by making the adjustable arm first a little high and then a little low, the resistance being calculated by simple proportion from the deflections obtained.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Resistance tested.	**Proportional arms.**		**Adjustable resistance.**	**Calculated resistance** $= \frac{\text{Right}}{\text{Left}} \times \text{IV.}$	**Remarks.**
	Left.	**Right.**			

Experiment No. R11.—Silvertown Testing Set (Insulation Resistance).

Introduction.—This method is essentially a method of direct deflections, a current flowing through the insulation resistance to be measured being compared with that flowing through a standard known resistance under the same E.M.F.

Diagram of Connections.—

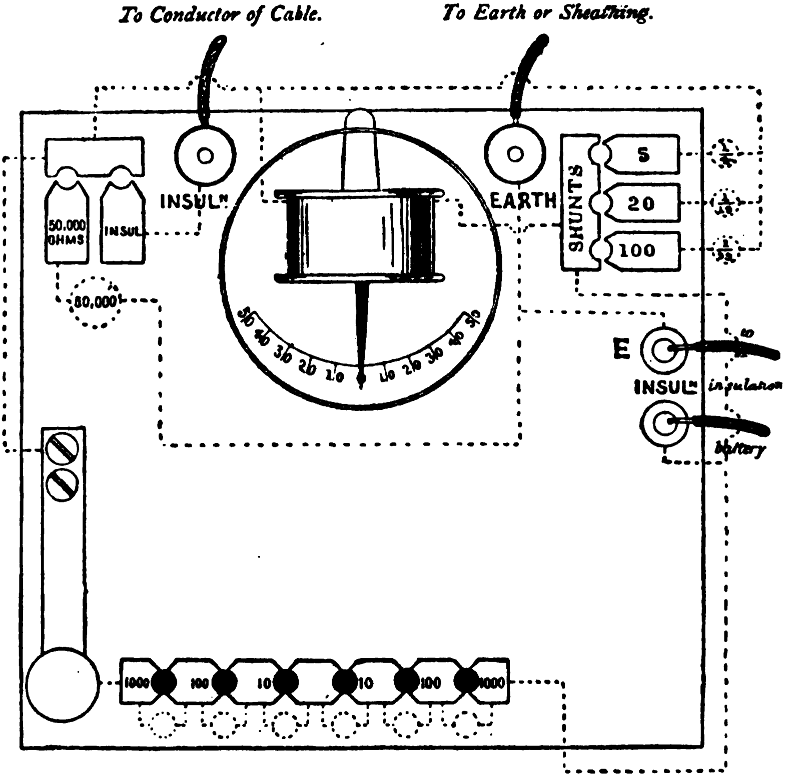


FIG. 20.

Apparatus required.—In the above diagram only those portions of the "set" used in this measurement are shown.

The apparatus consists of—

(1) A testing battery of Leclanché or similar cells to give 100–200 volts is connected to the terminals marked INSUL^{n}.

(2) The galvanometer and its shunts as shown.

(3) The conductor of the cable is connected to the terminals marked INSUL^n, and its sheathing, or a good earth connection, to that marked EARTH.

Method.—(1) Place the plug in the hole marked 50,000 ohms; shunt the galvanometer by placing the plug in the shunt marked 100 if a 200 volt-testing battery is used; in that marked 20 if the battery used gives 100 volts. Call the value of the shunt S and the deflection produced δ.

(2) Place the plug in the hole marked INSUL^n. Obtain a convenient deflection δ_1 (preferably as nearly equal to δ as possible) by using one of the shunts, 5, 20, or 100. Call the shunt used S_1, and the value of the insulation resistance to be measured R_1.

Then, if the galvanometer deflections are proportional to the currents producing them, we get—

$$R_1 . \delta_1 . S_1 = 50{,}000 . \delta . S$$

$$\text{Whence } R_1 = \frac{\delta . S}{\delta_1 . S_1} . 50{,}000$$

All the holes in the proportional arms are shown plugged up in the diagram of connections. As such, on tapping the key on the left-hand side it is placed as a short circuit across the galvanometer, and is useful for checking quickly any violent oscillations of the needle.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Insulation resistance tested.	R (50,000 ohms)	δ	S	δ_1	S_1	$R_1 = \frac{\delta . S}{\delta_1 . S_1} \times 50{,}000$	Remarks.

Experiment No. R12.—Internal Resistance of a Battery (Fall of Potential Method).

Introduction.—If a battery be connected up to an external circuit, the current caused to flow will be inversely proportional to the total resistance of the circuit, *i.e.* to the resistance of the external circuit plus that of the battery. There will thus be a potential drop in the battery itself which will be equal to the product of the current and the resistance of the battery (within certain limits). Hence, by measuring the potential difference of the terminals of a battery on "open circuit," *i.e.* when little or no current is passing, and again when a known current is passing, its resistance can be calculated by dividing the drop of potential by the current.

Diagram of Connections.—

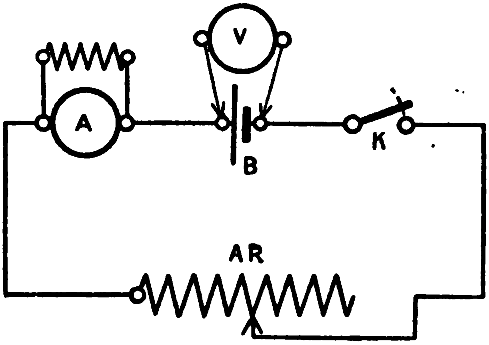


FIG. 21.

Apparatus required.—

B = battery whose resistance is to be measured.
V = low-reading high-resistance voltmeter (say, 3 volts and over 200 ohms).
A = ammeter.
AR = adjustable resistance.
K = key or switch.

Method.—(1) With K open, note the reading on V. This is the E.M.F. on open circuit = say E.

(2) Adjust AR to, say, 50 ohms, close K, and note the new reading E_1 on V, and the current C indicated on A, and for reference only, the resistance in AR.

(3) Decrease AR, and note about six simultaneous values of E_1 and C.

(4) Repeat (1), (2), and (3) for different types of cells and for different sizes of the same type.

Let E = E.M.F. on "open circuit,"
„ E_1 = voltage indicated when a current of C amps is flowing,
„ R = resistance of battery,

Then drop of potential in battery = $E - E_1$.

$$\therefore R = \frac{E - E_1}{C}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Battery tested.	E	E_1	C	$R = \frac{E - E_1}{C}$	AR	Remarks.

Experiment No. R13.—Resistance of Electrolytes (Kohlrausch Alternating-current Method).

Introduction.—The accurate measurement of the resistance of an electrolyte with a direct current method is almost impossible, and certainly very difficult, this being due to polarization taking place in the liquid. The effects can be greatly reduced by using electrodes of the same metal as in the salt, and can be almost entirely eliminated by a method employing alternating current in the measurement, in which case a telephone receiver is used in place of the usual galvanometer.

Kohlrausch recommends platinum electrodes covered with a film of platinum-black, as he found that by so doing the area of the surface was increased several thousand times. To prepare the surfaces of the electrodes in this manner, Messrs. Lummer and Kurlbaum * recommend platinization with a 3 per cent. solution of platinic chloride, containing about $\frac{1}{40}$th per cent. of lead acetate.

The actual measurement is best made by comparing the resistance so obtained with that of a standard solution (such as potassium chloride—KCl), measured in the same vessel and under exactly the same conditions. For a one-tenth normal solution of KCl (containing 7·46 grms. of KCl per litre of solution) Kohlrausch gives the following figures:—

Temperature.	Resistance per cm. cube.
15° C.	95·5 ohms.
16° C.	93·5 „
17° C.	91·6 „
18° C.	89·5 „
19° C.	87·5 „
20° C.	85·8 „
21° C.	84·0 „

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* *Verhandl der Phys. Gesellsch.*, 1895.

Diagram of Connections.—

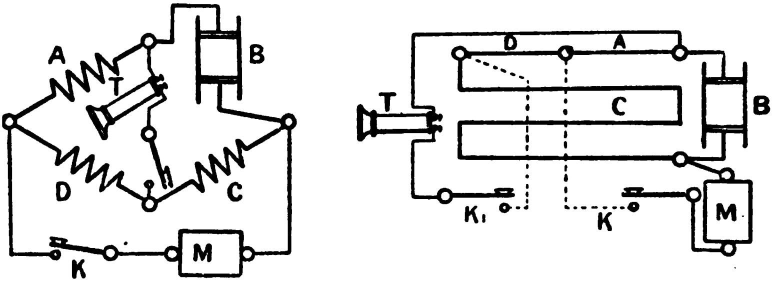

FIG. 22.

Apparatus required.—

A,D,C,K,K_1 = post office box or Wheatstone bridge (non-inductive resistances).
B = electrolytic cell to be measured.
T = telephone receiver for use as a galvanometer.
M = magneto, or other source of alternating current.

Method.—(1) Ensure that the electrolyte and the cell in which it is measured are thoroughly clean, as the presence of even slight quantities of foreign matters will materially affect the results.

(2) Adjust A, D, and C for high values, and start the magneto. A buzzing noise will be heard in the telephone. Adjust arm C until the buzzing noise entirely disappears, or, if this condition is unattainable, until the noise is a minimum. To get an exact balance, it will be found an advantage to alternately increase and decrease C so as to obtain an alternately increasing and decreasing sound in T; then, by reducing the amplitude of variation of C, the point of minimum noise can be detected to a nicety.

(3) Insert different values in arms A and D, and repeat (2).

(4) Repeat (2) and (3) for different temperatures of the same electrolyte.

(5) Repeat (2) and (3) for different densities of the electrolyte, but all at the same temperature.

(6) Thoroughly clean the vessel B and the electrodes, and fill with the standard solution. Carefully note the temperature and make two or three accurate measurements.

Let B = resistance of electrolyte in arm B,

$$\text{Then } B = \frac{A}{D} \times C \text{ ohms.}$$

Let KCl = resistance of KCl solution found as above,
ρ_{KCl} = specific resistance of KCl corresponding to its temperature (as given above),
ρ = specific resistance of electrolyte,

$$\text{Then } \rho = \rho_{KCl} \cdot \frac{B}{KCl}.$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Electrolyte.	Density.	Temperature.	Resistances.			$B = \frac{A}{D} \cdot C$	$\rho = \rho_{KCl} \cdot \frac{B}{KCl}$	Remarks.
			A	D	C			
								Room temperature ° C.

Plot the following curves:—

(*a*) Electrolyte of same density—temperatures as ordinates, and ρ's as abscissæ.

(*b*) For electrolytes at same temperatures—densities as ordinates, and ρ's as abscissæ.

CHAPTER IV

MEASUREMENT OF E.M.F.

Experiment No. E1.—Equal Resistance Method.

Introduction.—This method of comparison of E.M.F.'s depends on the fact that if the total resistances of two circuits are equal, the E.M.F.'s applied to the circuits are proportional to the currents in the respective circuits. It is, of course, preferable to employ the same external circuit for both E.M.F.'s, comparison being made between them by substituting one for the other, and noting their respective currents. Also, on account of polarization of the cells, the resistance of the external circuit should be large; and since the method is a substitution one, in which the resistance as well as E.M.F. of one cell is substituted for the other, the relative resistance of external circuit to that of the source of E.M.F. should also be large.

Diagram of Connections.—

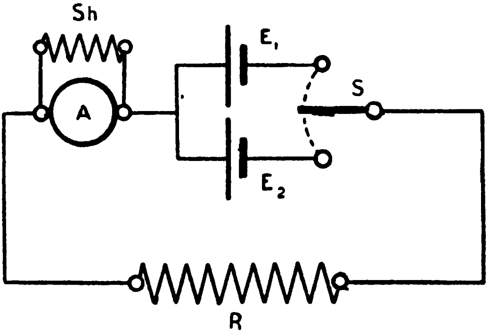

FIG. 23.

Apparatus required.—

E_1, E_2 = sources of E.M.F. to be compared, one of which, say E_1, may be known; *e.g.* a standard cell.
R = large external resistance.
A = low-reading ammeter.
Sh = shunt on A (if necessary)
S = two-way switch.

Method.—(1) Connect up as in the diagram, and adjust R for a high value (say 1000 to 10,000 ohms).

(2) Place S on E_1, and adjust Sh or R to give a convenient deflection. Note the deflection δ_1 on A and, for reference only, R.

(3) Place S on E_2, and, with Sh and R unaltered, note the new deflection δ_2 on A.

(4) Repeat (2) and (3) for E_1 and E_2, but with different initial values of δ_1 (and therefore of δ_2) by altering Sh or R.

(5) Repeat (2), (3), and (4) for different cells.

Let E_1 = E.M.F. of standard cell,
E_2 = unknown E.M.F. of other cell,
δ_1 = deflection on A due to E_1,
δ_2 = ,, A ,, E_2,

Then, if A is an ammeter, *i.e.* an instrument indicating current directly—

$$\frac{E_1}{E_2} = \frac{\delta_1}{\delta_2}$$

$$\therefore E_2 = E_1 \cdot \frac{\delta_2}{\delta_1}$$

If a galvanometer be used, *e.g.* a tangent galvanometer, tan δ_1 and tan δ_2 will be substituted for δ_1 and δ_2 in the above; and the best values of δ_1 and δ_2 for maximum accuracy obtained from the tangent curve plotted in Experiment No. 1, Chap. I.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Cell E_1.	**E.M.F. of E_1.**	**Cell E_2.**	**δ_1.**	**δ_2.**	**$E_2 = E_1 \cdot \frac{\delta_2}{\delta_1}$**	**Remarks.**
						R = ____ ohms A = ____ ,, Sh = ____ ,,

Experiment No. E2.—Equal Deflection Method.

Introduction.—This method of comparing E.M.F.'s corresponds to the substitution method of measuring resistance. If the total resistances of the circuits supplied with the E.M.F.'s to be compared are so adjusted that equal currents flow through them, then, from Ohm's law, the E.M.F.'s will be proportional to the respective total resistances of the circuits. If the resistances of the external circuits be made very large in comparison with those of their respective internal circuits (cells), their values will represent, very nearly, their respective E.M.F.'s

Diagram of Connections.—

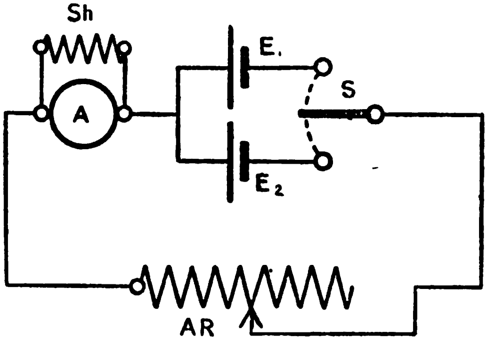

FIG. 24.

Apparatus required.—

E_1, E_2 = sources of E.M.F. to be compared, one of which, say E_1, may be known.
AR = large adjustable known resistance.
A = low-reading ammeter.
Sh = shunt on A (if necessary).
S = two-way switch.

Method.—(1) Connect up as above; insert a large resistance in AR (say 1000 to 10,000 ohms).

(2) Place S on E_1, and adjust Sh or AR to give a convenient deflection δ_1 on A. Note R_1 and, for reference, Sh.

(3) Place S on E_2, and, with Sh unaltered, adjust AR to give the same deflection δ on A. Note R_2.

(4) Repeat (2) and (3) for E_1 and E_2 for different values of δ on A, noting the respective values of R_1 and R_2 for the same deflection.

(5) Repeat (2), (3), and (4) for different sources of E.M.F.

Let E_1 = E.M.F. of standard cell,
E_2 = unknown E.M.F. of other cell,
R_1 = resistance of AR for δ with E_1,
R_2 = „ AR „ δ „ E_2,

Then, since the current is the same in both cases—

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

$$\therefore E_2 = E_1 \cdot \frac{R_2}{R_1}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Cell E_1.	E.M.F. of E_1.	Cell E_2.	R_1.	R_2.	$E_2 = E_1 \cdot \frac{R_2}{R_1}$	Remarks.
						δ on A = ____ Resistance of A = ____ ohms Resistance of Sh = ____ ohms

Experiment No. E3.—Wiedemann's or Sum-and-Difference Method.

Introduction.—This method consists in placing the E.M.F.'s to be compared in series, first, assisting each other; and, secondly, opposing each other; and comparing the respective currents sent through the same external circuit. The resistance of the external circuit is made large enough to reduce the current flowing to a value having no appreciable polarization effect on the cells.

Diagram of Connections.—

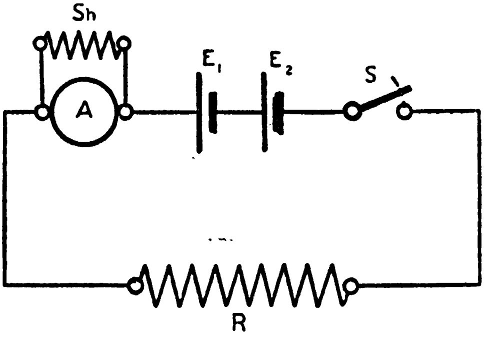

FIG. 25.

Apparatus required.—

E_1, E_2 = sources of E.M.F. to be compared, one of which, say E_1, may be known.
R = high resistance.
A = low-reading ammeter.
Sh = shunt on A (if necessary).
S = switch or key.

Method.—(1) Connect up as above, with E_2 assisting E_1.

(2) Close S, and adjust R and Sh for a large reading on A, taking care that R is of large value (say 1000 ohms). Note reading on A, δ_1, and, for reference, the value of R.

(3) With R and Sh unaltered, connect E_2 in opposition to E_1, close S and note the new deflection on A, δ_2. (NOTE.—If E_2 is greater than E_1, δ_2 will be in the reverse direction to δ_1. With instruments which deflect in one direction only, it would therefore, in such a case, be necessary to change the positions of E_1 and E_2. With an instrument whose deflections can be measured in either direction this is not necessary, but care should be taken to note the negative sign of δ_2.)

(4) Repeat (2) and (3) for different values of δ_1 obtained by altering Sh, noting the respective values of δ_1 and δ_2 for the same conditions of external circuit.

(5) Repeat (2), (3), and (4) for different sources of E.M.F.

Let E_1 = E.M.F. of standard cell.
E_2 = unknown E.M.F. of other cell,
δ_1 = deflection on A due to $E_1 + E_2$,
δ_2 = „ „ A „ $E_1 - E_2$.

Then, if δ_1 and δ_2 are proportional to their respective currents—

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{\delta_1}{\delta_2}$$

Multiplying across, we get

$$E_1\,\delta_2 + E_2\,\delta_2 = E_1\,\delta_1 - E_2\,\delta_1$$
$$\therefore E_2\,(\delta_1 + \delta_2) = E_1\,(\delta_1 - \delta_2)$$
$$\textit{i.e.}\ \frac{E_1}{E_2} = \frac{\delta_1 + \delta_2}{\delta_1 - \delta_2}$$

If E_1 is known—

$$E_2 = E_1 \cdot \frac{\delta_1 - \delta_2}{\delta_1 + \delta_2}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Cell E_1.	E.M.F. of E_1.	Cell E_2.	δ_1.	δ_2.	$E_2 = E_1 \cdot \frac{\delta_1 - \delta_2}{\delta_1 + \delta_2}$	Remarks.
						R = ____ ohms A = ____ „ Sh = ____ „

Experiment No. E4.—Lumsden's Method.

Introduction.—This method is based on the fact that if two sources of E.M.F. be connected in series, and with an external circuit, there will be a point in that external circuit at the same potential as the common point between the two cells; and that the E.M.F.'s of the sources will be proportional to the resistances on their respective sides of the circuit thus divided.

Diagram of Connections.—

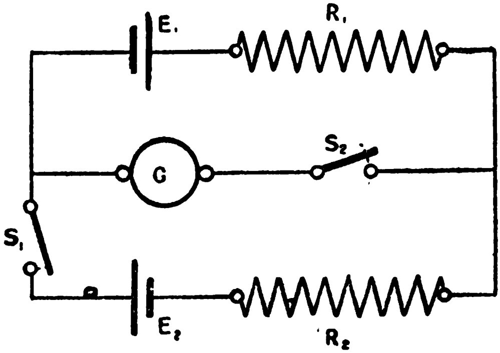

Fig. 26.

Apparatus required.—

E_1 E_2 = sources of E.M.F. to be compared, one of which, say E_1, may be known.

R_1 R_2 = known high resistances (say above 1000 ohms), one of which (say R_2) can be varied.

G = sensitive high-resistance galvanometer.

S_1 S_2 = switches or keys.

Method.—(1) Connect up as above with E_2 assisting E_1.

(2) Close S_1 and adjust R_2 so that on closing S_2 no deflection is obtained on G. Note R_1 and R_2.

(3) Repeat (2) for different values of R_1, and obtain the corresponding values of R_2, noting R_1 and R_2 in each case.

(4) Repeat (2) and (3) for different sources of E.M.F.

Let E_1 = E.M.F. of standard cell,
E_2 = unknown E.M.F. of other cell,
R_1 = resistance on side E_1,
R_2 = " " E_2,

Then, if the cells are of small resistance compared with R_1 and R_2,

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

$$\therefore E_2 = E_1 \cdot \frac{R_2}{R_1}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Cell E_1.	E.M.F. of E_1.	Cell E_2.	R_1.	R_2.	$E_2 = E_1 \cdot \frac{R_2}{R_1}$	Remarks.

Experiment No. E5.—Clark-Poggendorff Method.

Introduction.—This method depends upon the fact that the fall of potential between any two points in a circuit is proportional to the resistance between them. The E.M.F.'s to be compared are balanced against the fall of potential over a portion of a circuit fed by a "working" battery; the ratio of the resistances of the portions of the circuit balanced is also the ratio of the E.M.F.'s, providing the current through the circuit (*i.e.* the total resistance and the working E.M.F.) have remained constant.

Diagram of Connections—

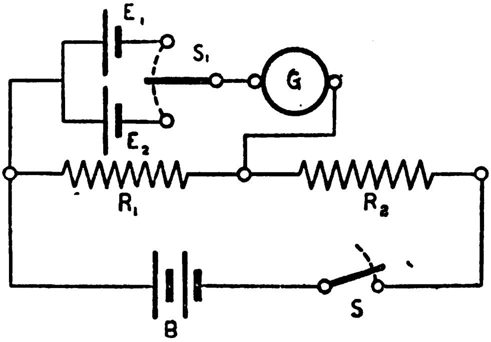

FIG. 27.

Apparatus required.—

E_1 E_2 = E.M.F.'s to be compared, one of which, say E_1, may be known.

R_1 R_2 = resistance boxes in series, capable of adjustment so that $R_1 + R_2$ may be kept constant, and about 10,000 ohms.

S = switch in circuit of working battery.
S_1 = two-way switch.
B = working battery.
G = sensitive high-resistance galvanometer.

Method.—(1) Connect up as above, joining all like poles to the same point.

(2) If B is of two cells, make R_1 and R_2 about 5000 ohms each, and close S. Place S_1 on E_1, and adjust R_1 until a balance is indicated by no deflection on G. Note R_1 and $R_1 + R_2$.

(3) Place S_1 on E_2, and obtain a balance by adjusting R_1 and R_2 simultaneously, so that their total resistance is the same as formerly. Note the new value of R_1, say R_3.

(4) Place S_1 on E_1, and check operation (1) for constancy of E.M.F., taking the mean of the two values of R_1 obtained.

(5) Repeat (2), (3), and (4) for different values of $R_1 + R_2$, and for different cells.

Since the total resistance of the circuit was maintained constant throughout—

$$E_1 : E_2 = R_1 : R_3$$

and E_1 being known, we get—

$$E_2 = E_1 \cdot \frac{R_3}{R_1}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Cell E_1.	E.M.F. of E_1.	Cell E_2.	R_1.	R_3.	$E_2 = E_1 \cdot \frac{R_3}{R_1}$	Remarks.
						$R_1 + R_2 =$ ____ ohms

CHAPTER V

MEASUREMENT OF CURRENT

Experiment No. C1.—Electrolysis of Copper-Sulphate Method.

Introduction.—The principle of the electrolytic methods of measuring current strength may be stated by the following quantitative laws of electrolysis:—

(1) The amount of chemical action is equal at all points of a circuit.

(2) The amount of an ion liberated at an electrode in a given time is proportional to the strength of a current.

(3) The amount of an ion liberated at an electrode in one second is equal to the strength of the current multiplied by the "electro-chemical equivalent" of the ion.

Let w = weight of an ion liberated,
C = current strength,
t = time in seconds,
z = electro-chemical equivalent,

Then the above laws give the following formula:—

$$w = Ctz$$

w is usually measured in grms., c in ampères, and t in seconds.

So that z, the electro-chemical equivalent, is the amount in grms. of an ion liberated by an ampère flowing for one second.

The "chemical equivalent" of an ion can be obtained from the formula—

$$\text{Chemical equivalent} = \frac{\text{atomic weight}}{\text{valency}}$$

The "electro-chemical equivalent," z, can be calculated from the formula—

$$z = \text{chemical equivalent} \times 0{\cdot}000010384.$$

0·000010384 being the number of grms. of hydrogen liberated by one ampère flowing for one second (*i.e.* one coulomb), the atomic weight, valency, and chemical equivalent of hydrogen each being unity.

Thus, the atomic weight of copper = 63·18, and its valency = 2 (cupric), so that its chemical equivalent = 31·59, and its electro-chemical equivalent $z = 31{\cdot}59 \times 0{\cdot}000010384 = 0{\cdot}0003281$.

One ampère flowing for one second will deposit 0·0003281 grms. of copper.

The experiment consists in passing the current to be measured through a solution of copper sulphate for a known time; by weighing the amount of copper deposited on the cathode plates, the average strength of the current passing during that time can be calculated.

Diagram of Connections.—

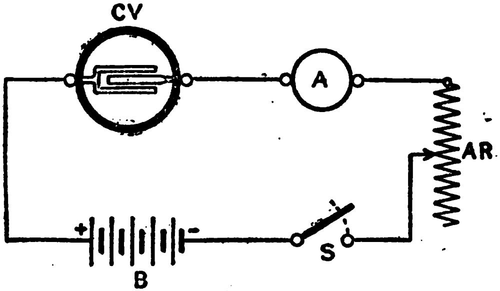

FIG. 28.

Apparatus required.—

CV = copper voltameter, having one more anode than cathode plates. The total surface (both sides) of the cathode plates immersed in the solution should not be less than 50 sq. cms. per ampère.* The solution is made by dissolving enough pure copper-sulphate crystals in clean water to produce a saturated solution of specific gravity 1·18, to which is added 1 per cent. of strong sulphuric acid.

A = current indicating instrument to verify the constancy of the current.

B = source of constant current.

AR = adjustable resistance.

S = switch.

A watch, acid bath, and a drying cupboard.

Method.—(1) Having ascertained their number and size for the current to be measured, the cathode plates should be well cleaned in a bath of commercial nitric acid, rinsed well with clean water, afterwards carefully dried with clean white blotting paper, and finally

---

[*] This means a *current density* of 0·02 amp. per sq. cm. of cathode plate surface. For a greater current density than this the deposit will be non-adherent.

dried in the drying cupboard. After being accurately weighed, they should be immediately placed in position in the voltameter.

(2) Make sure that the positive of the battery is connected to the anode of the voltameter; close S, and note the time and, incidentally, the reading on A.

(3) Keep the current flowing for, say, 30 minutes, maintaining its value constant (as indicated on A) by means of AR.

(4) Open S and note the exact time.

(5) Remove the cathode plates, taking care that the surfaces are untouched during the process. Rinse them in slightly acidulated, and then in clean, water, and place in the drying oven.

(6) When dry and cool, their new weight should be accurately determined.

Let W = original weight of cathode plates in grms. (1).
W_1 = final „ „ „ (6).
w = amount of copper deposited on the cathode plates in grms.
t = time of the current flowing in seconds.

Then $w = W_1 - W = Ctz$.

$$\therefore C = \frac{w}{t \times 0{\cdot}0003281} \text{ amps.}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
W (grms.)	W_1 (grms.)	$w = (W_1 - W)$ (grms.)	t (secs.)	$C = \frac{w}{t \times 0{\cdot}0003281}$ amps.	Remarks.
					Area of cathode plate = —— sq. cms. Area per amp. = —— sq. cms. Temperature of voltameter = ——° C.

Experiment No. C2.—Electrolysis of Silver Nitrate Method.

Introduction.—The principles of this method are the same as those explained in the previous experiment, but on account of the electro-chemical equivalent of silver being about three times that of copper, its employment lends itself to a greater accuracy of current measurement. For these reasons it forms a standard method of current measurement, being replaced by the more frequent method of copper deposition only on the score of economy.

Diagram of Connections.—

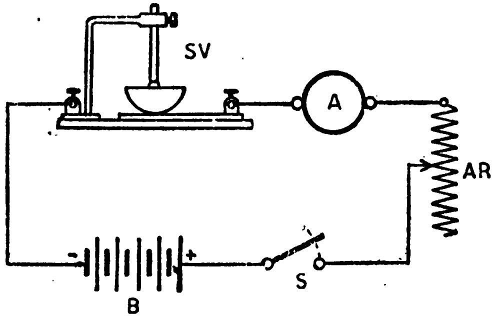

Fig. 29.

Apparatus required.—

SV = silver voltameter, having the cathode in the form of a bowl about 3 inches in diameter and made of platinum, so that the inside of the bowl may be cleaned by dissolving the deposited silver in nitric acid to form silver nitrate, which can be used again. The anode is made of a round flat plate of pure silver, and is, during an experiment, temporarily wrapped in a good filter-paper to ensure the purity of the deposit on the bowl underneath. The electrolyte should consist of a neutral solution composed of 15 per cent. by weight of pure silver nitrate to 85 per cent. of pure water.

A = current-indicating instrument to verify the constancy of the current passing.

B = source of constant current (say about 1 ampère).*

AR = adjustable resistance.

S = switch.

A watch, acid bath, and drying cupboard.

Method.—(1) Clean the platinum bowl first in nitric acid, then in clean water; dry it in the drying cupboard, and weigh it as accurately as possible when cool.

(2) Place the bowl in position with the silver disc and its covering of good filter-paper symmetrically above it, and pour in enough electrolyte to cover the disc. Adjust the current by means of AR to about 1 amp.; this is preferably done by temporarily disconnecting

---

* This is the correct current for a bowl 3 inches in diameter. For any other size of bowl, the current should be adjusted accordingly.

SV and completing the circuit, opening S, and then reconnecting SV. Close S, and note the exact time and, incidentally, the reading on A.

(3) Keep the current constant by means of AR, and let it flow for about 30 minutes. Open S and note the time.

(4) Take out the platinum bowl and, having emptied the solution into a bottle (for future use), wash the deposited silver with distilled water, and allow the bowl to stand filled with clean water for a short time. Rinse it out with clean water, and finally with alcohol, and dry in the drying oven.

(5) When dry and cool, the new weight of the bowl should be accurately determined.

Let W = original weight of cathode in grms. (1),
W_1 = final " " " (5),
w = amount of silver deposited on the cathode bowl in grms.,
t = time of the current flowing in seconds,

$$\text{Then } w = W_1 - W = Ctz$$

$$z \text{ for silver} = 0{\cdot}00118 \text{ grms. per amp. second.}$$

$$\therefore C = \frac{w}{t \times 0{\cdot}001118} \text{ amps.}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
W (grms.)	W_1 (grms.)	$w = (W_1 - W)$ (grms.)	t (secs.)	$C = \frac{w}{t \times 0{\cdot}001118}$ amps.	Remarks.
					Area of cathode plate = —— sq. cms. Area per amp. = —— sq. cms. Temperature of voltameter = ——° C.

Experiment No. C3.—Mixed Gas Voltameter Method.

Introduction.—Read the introduction to Experiment C1.

The electrolyte is a 20 per cent. solution of caustic soda and water, the electrodes being of iron. The mixed gas evolved is led to a measuring tube of known volume.

Let V = actual volume of gas liberated (c.cms.),
P = pressure to which it is subjected (mms. of mercury),
T = absolute temperature of gas ($273 + \theta°$ C.),
θ = observed temperature of gas ——° C.

Then, from the laws of gases—

$$\frac{V_0P_0}{T_0} = \frac{V \cdot P}{T},$$

where V_0 is the volume at zero temperature T_0 (273° C. absolute) and normal pressure P_0 (760 mms. of mercury).

Referring now to the collecting rule shown in the diagram above, if the level of the water in it be displaced to that of the electrolyte in the jar, then the *actual* pressure to which the gas is subjected is—

$$P = B - p,$$

where B = height of barometer in mms.,*

p = pressure of aqueous vapour at θ° C.

The relation between θ and p is as follows:—

θ° C.	6	8	10	12	14	16	18	20
p mms. of mercury	7·0	8·0	9·1	10·4	11·9	13·5	15·3	17·4

From the above expression, the value of V_0 is obviously—

$$V_0 = \frac{273V(B - p)}{760T}.$$

Diagram of Connections.—

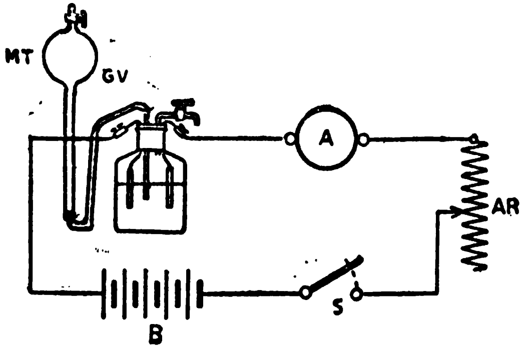

FIG. 30.

Apparatus required.—

GV = gas voltameter with measuring tube MT.

A = current-indicating instrument to verify the constancy of the current.

B = source of constant current. AR = adjustable resistance.

S = switch. A watch.

---

* The correction for the temperature of the barometer amounts to about 1·8 mms. at 15° C., and this amount should be subtracted from the observed height.

Method.—(1) Completely fill the tube MT with water and invert in the bath. Make all joints, etc., gas-tight, and connect the tube between GV and MT.

(2) Adjust AR for a small indication on A (which must be kept absolutely constant throughout) and close S, noting the exact time of doing so.

(3) As the tube MT gets nearly full of gas, carefully note the exact time when the water-level drops to that of the water in GV. Call the time to fill the tube *t* secs., and the constant current C amps.

(4) Repeat for the same value of C, and then for other values of C, making two experiments for each value.

$$\text{Then } M_H = C \,.\, t \,.\, Z_H, \quad \text{and } M_0 = C \,.\, t \,.\, Z_0,$$

where M_H, M_0, Z_H, and Z_0 are the grams liberated, and the electrochemical equivalents of hydrogen and copper respectively.

The volume of 1 grm. of H at normal temperature and pressure is 11,200 c.cms.; so that the volume of O at normal temperature and pressure is $\frac{11,200}{16}$ c.cms.

$$\left.\begin{array}{r}\text{From this, there-}\\ \text{fore, } V_0\end{array}\right\} = C \,.\, t \,.\, Z_H \times 11,200 + C \,.\, t \,.\, Z_0 \times \frac{11,200}{16} \text{ c.cms.}$$

$$\text{and } C = \frac{V_0}{t(11,200Z_H + \frac{11,200}{16}Z_0)}$$

Substituting for V_0, and taking $Z_H = 0{\cdot}000010384$, and $Z_0 = 8Z_H$, we get—

$$C = \frac{273V(B - p)}{760T \times 0{\cdot}1744t} \text{ amps.}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
C indicated on A.	Time at start.	Time at finish.	Time to evolve volume, V, of gas, *t* (secs.).	Current, C, amps. (calculated).	Remarks.
	h. m. s.	h. m. s.			B —— mms. p —— mms. V —— cu. cms. θ ——° C. T=273+θ ____° C. abs.

Experiment No. C4.—Heating Effect Method.

Introduction.—From theoretical considerations it is known that one joule—a volt-amp.-second—is approximately equivalent to 0·238 calories, or to that amount of heat required to raise the temperature of one grm. of pure water by 0·238° C. A measurement of the heating effect of a current flowing through a resistance immersed in a known weight of water will therefore provide a means of calculating the value of the current. The practical realization, with great accuracy, of the measurement of the heat evolved involves many difficulties on account of loss of heat by radiation, etc., so that the following method gives approximate results only; with care, however, an accuracy of 1 per cent. can be obtained.

Diagram of Connections.—

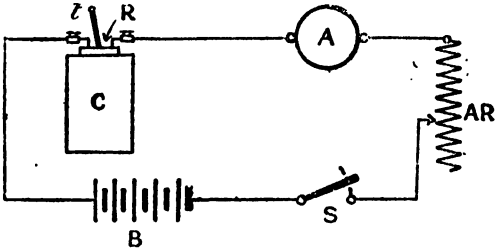

Fig. 31.

Apparatus required.—

C = calorimeter carefully insulated to prevent loss of heat.
R = known resistance immersed in the water in C.
t = accurate thermometer.
B = source of constant current.
A = ammeter in main circuit.
AR = adjustable resistance.
S = switch. Stop watch.

Method.—(1) Weigh the calorimeter, and place in it a known weight of clean water. Place the thermometer, *t*, in the water, and do not commence the experiment until the reading on *t* is steady (the water being well stirred), and care has been taken to finally ensure C being well insulated.

(2) Adjust AR for a small current indicated on A (depending on the value of R and the weight of water in C); close S, and note the exact time.

(3) Keep the current C constant by means of AR, and allow it to flow until the temperature of the water has risen about 10° C. Note the exact time of switching S off, and the exact reading of *t*, the water being kept well stirred.

(4) Place fresh water in the calorimeter, and repeat (2) and (3)

for increasing currents, but for about the same rise in temperature, noting carefully in each case the exact times of closing and opening S, the weight of water in C, and the rise of temperature.

Let C = current in ampères,
R = resistance of the coil in ohms,
t = time current flows in seconds,

$$\text{Then calories of heat produced} = 0{\cdot}238\ C^2Rt.$$

Let W = weight in grms. of water in C,
W_1 = " " calorimeter,
T_1 = initial temperature of water and C——° C.,
T_2 = final temperature of water and C——° C.,
S_1 = specific heat of material of calorimeter,

Then calories of heat given to water and calorimeter—

$$= (W + W_1S_1)(T_2 - T_1)$$

Then, neglecting heat given to stirrer, thermometer, and resistance itself, and that lost by radiation, etc. (all usually negligible quantities) *—

$$0{\cdot}238\ C^2Rt = (W + W_1S_1)(T_2 - T_1)$$

$$\therefore C = \sqrt{\frac{(W + W_1S_1)(T_2 - T_1)}{0{\cdot}238\ R\,.\,t}}\ \text{amps.}$$

Results.—Tabulate your results thus:—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
W (grms.)	W_1 (grms.)	S_1	R	Times.			$(T_2 - T_1)$ °C.	$= C\sqrt{\frac{(W+W_1S_1)(T_2-T_1)}{0{\cdot}238\ R\,.\,t}}$	Remarks.
				Closing S	Opening S	t (secs.)			
									Room temperature ° C.

---

* In the author's laboratory the water equivalent of these three was about 6 grms. The weight W_1 (copper) was about 70 grms., whilst W was usually about 200 grms., giving $(W + W_1S_1)$ = about 207 grms. In this case the 6 grms. was not negligible.

The loss due to radiation can be much reduced by applying a large current for a short time only; for, say, less than 10 minutes.

CHAPTER VI

THE POTENTIOMETER

For the measurement of E.M.F., current, and resistance, the use of the potentiometer method is now universal. The peculiar property of the method is that the leads or wires connecting the apparatus under test to the potentiometer wire carry no current when the observation is taken; they serve only to communicate to the potentiometer the difference of potential of the points to which they are attached. Their mode of attachment, resistance, and, generally, the errors introduced into the majority of measurements by ordinary methods, due to the above and a number of unavoidable causes, including contact resistances, have therefore no effect on measurements made by this process. The principle of the method may be stated as follows:—

A long uniform wire (having the same resistance per unit length throughout) is supplied with a constant current of electricity from a battery.

Since the wire is uniform in resistance, the potential drop per unit length will also be uniform throughout, and a given length of wire will represent the potential drop along it. The method consists in measuring—

(*a*) **E.M.F.'s** by comparing the length of wire to produce a balance with that to balance a standard cell of known E.M.F.

(*b*) **Current** by comparing the length of wire to produce a balance with the potential drop in a known resistance through which the current is passing with that length to balance the E.M.F. of a standard cell, the current being calculated by Ohm's law.

(*c*) **Resistance** by passing the same current through the unknown and a known resistance, and comparing the lengths of potentiometer wire to produce a balance with the potential drop in each case.

In actual practice the accuracy required in measurement involves the use of a very long potentiometer wire. For convenience a large proportion of the total length used is made up into resistance coils, the remaining portion only retaining the form of a long uniform wire.

Experiment No. P1.—The Potentiometer (Measurement of E.M.F.).

Introduction.—The fall of potential between two points on a uniform wire carrying a current is proportional to the length of wire between them.

The E.M.F. to be measured is balanced against a length of such a wire, and a known E.M.F. balanced against another length of the wire.

The E.M.F.'s, being directly proportional to their respective lengths of potentiometer wire, and one E.M.F. being known, the other can be calculated.

(A) **Low E.M.F.**

Diagram of Connections.—

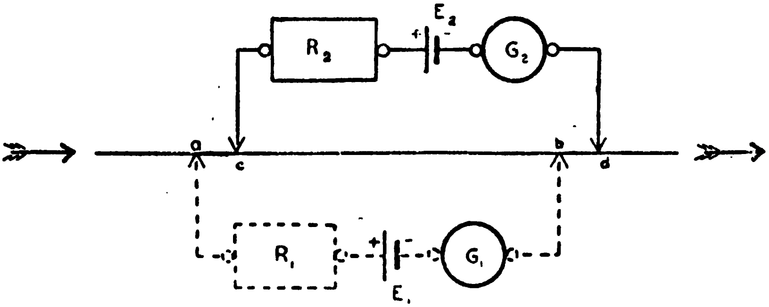

FIG. 32A.

Apparatus required.—

acbd = potentiometer wire.

R_1R_2 = high resistances (R_1 for circuit E_1 about 10,000 ohms).

E_2 = unknown E.M.F.

E_1 = standard cell.

G_1G_2 = sensitive galvanometer.

Method.—(1) Connect up circuit E_1, etc., only so as to oppose the E.M.F. in the wire, and with R_1 in circuit obtain a balance on G_1 by fixing the point *a* and finding point *b*. The length of *ab* can be more accurately determined by removing a part or the whole of R_1; but this is undesirable with a standard cell in circuit, and resource should preferably be made to a very sensitive galvanometer G_1.

Measure the length *ab*.

(2) Disconnect circuit E_1, etc., and connect up circuit E_2, etc. Choose any point *c* and find *d* for an approximate balance, obtaining a more accurate balance by removing a part or the whole of R_2.

Measure the length *cd*.

NOTE.—The current flowing through the potentiometer wire should be constant throughout, which can be verified by again balancing E_1, when the length *ab* should be the same.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
E.M.F. to be measured, E_2.	Length to balance standard $= ab$.	Length to balance, $E_2 = cd$.	E.M.F. of standard $= E_1$.	E.M.F. of $E_2 = E_1 \cdot \frac{cd}{ab}$	Remarks.

(B) **High E.M.F.**—The high E.M.F. E is connected to a resistance, and the fall of potential along a known fraction of this is measured as above; the fraction being known, the whole may be calculated.

Diagram of Connections.—

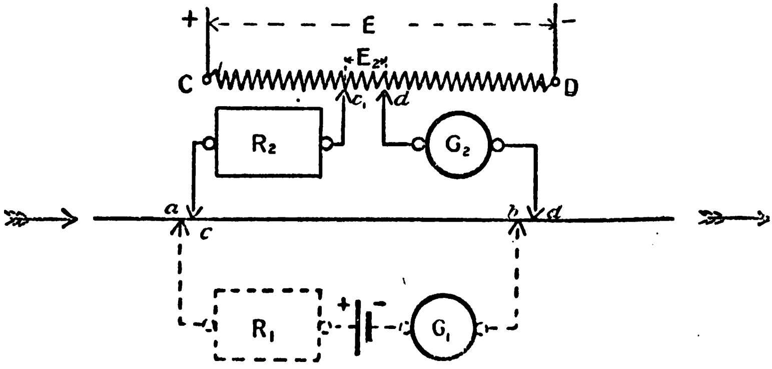

FIG. 32B.

Apparatus required as above; also a high resistance CD, of which a known fraction c_1d_1 can be tapped off.

Method as before. Note the ratio CD : c_1d_1.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
E.M.F. to be measured, E.	Length to balance standard = *ab*.	Length to balance $E_2 = cd$.	E.M.F. of standard $= E_1$.	Ratio $\frac{CD}{c_1d_1} = X$	E.M.F. $E = E_1 \cdot \frac{cd}{ab} \cdot X$.	Remarks.

Experiment No. P2.—The Potentiometer (Measurement of Current).

Introduction.—The current to be measured is passed through a suitable known resistance having a negligible temperature coefficient (usually a strip of manganin or a number of manganin wires in parallel), and the potential drop in this resistance, due to the current passing, is balanced against the potential drop in a portion of the potentiometer wire. Knowing the length of wire in which the potential drop balances that of a standard cell, the first can be calculated, and, the resistance being known, the current is found by Ohm's law.

Diagram of Connections.—

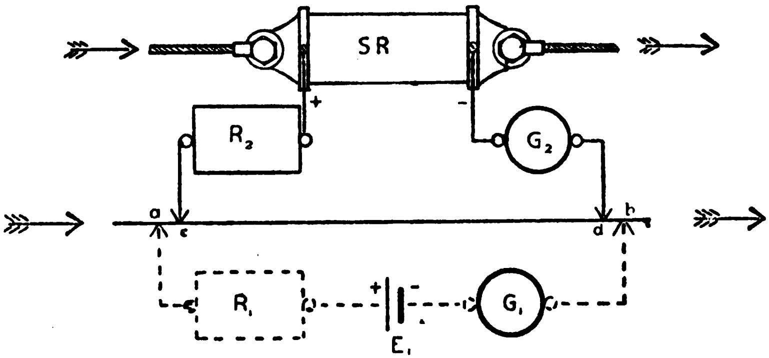

Fig. 33.

Apparatus required.—

abcd = potentiometer wire.
SR = standard resistance.
R_1R_2 = high resistances (R_2 for circuit E_1 about 10,000 ohms).
E_1 = standard cell.
G_1G_2 = sensitive galvanometers.

Method.—(1) Connect up circuit E_1 only, so as to oppose the E.M.F. in the potentiometer wire. With R_1 in circuit obtain a balance on G_1 by fixing the point A and finding B. Obtain a more accurate balance by gradually decreasing R_1, and measure the length *ab*.

(2) Disconnect circuit E_1, etc., and connect up circuit E_2, etc., so as to oppose the E.M.F. in the potentiometer wire. Obtain an approximate balance on G_2, and a more accurate balance at the points *cd* by decreasing R_2. Measure the length *cd*.

NOTE.—The constancy of the current in the potentiometer wire should be verified by again balancing E_1, when the length *ab* should be the same as formerly.

Let C = current to be measured in ampères,
„ SR = standard resistance in ohms,
„ E_2 = fall of potential in SR when C is passing,
„ E_1 = E.M.F. of standard cell (for Clark's cell = 1·434 volts at 15° C.),

$$\text{Then } E_2 = E_1 \cdot \frac{cd}{ab}$$

And since $E_2 = C \times SR$

$$\therefore C \times SR = E_1 \cdot \frac{cd}{ab}$$

$$\therefore C = \frac{E_1}{SR} \cdot \frac{cd}{ab}$$

Of these E_1 and SR are known, and *cd* and *ab* are measured, so that C can be directly calculated.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Length to balance standard = *ab*.	Length to balance E_2 = *cd*.	E.M.F. of standard = E_1.	Standard resistance = SR.	Current, $C = \frac{E_1}{SR} \cdot \frac{cd}{ab}$	Remarks.

Experiment No. P3.—The Potentiometer (Measurement of Resistance).

Introduction.—The resistance to be measured is compared with a known resistance by comparing the length of potentiometer wire to balance the drop in it, with the length to balance the drop in a known resistance carrying an equal, and preferably the same, current. For this purpose the known and the unknown resistances are connected in series, and traversed by a current of a value (which need not be known) large enough to give a convenient drop of potential in the resistances. The resistances are then directly proportional to their respective lengths of potentiometer wire.

Diagram of Connections.—

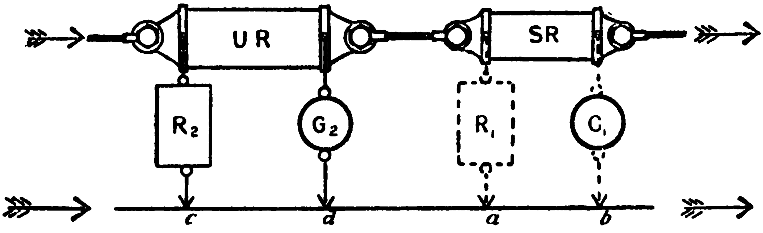

Fig. 34.

Apparatus required.—

cdab = potentiometer wire.
SR = standard resistance.
UR = unknown resistance.
R_1R_2 = high resistances.
G_1G_2 = sensitive galvanometers.

Method.—(1) Connect up circuit SR, etc., so as to oppose the E.M.F. in the potentiometer (as in the diagram), and with R_1 in circuit choose a convenient length *ab*, and adjust the current through UR and SR to give an approximate balance. This current must remain constant throughout. Obtain a more accurate balance by decreasing R_1 (if necessary to zero), and measure the length *ab*.

(2) Disconnect circuit SR, etc.; from the potentiometer wire, connect up circuit UR, etc.; and obtain an approximate, and finally an accurate, balance as before. Measure the length *cd*.

Note.—Verify the constancy of both currents (that in the potentiometer wire, and that through the resistances) by repeating (1) when *ab* should be the same as formerly.

Let SR = standard resistance in ohms,
UR = unknown resistance in ohms,
ab and *cd* = as shown,

Then SR : UR = $ab : cd$.

$$\therefore \text{UR} = \text{SR} \cdot \frac{cd}{ab}$$

Of these factors SR is known, and cd and ab are measured, so that UR may be directly calculated.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Unknown resistance, UR.	Standard resistance, SR in ohms.	length ab.	length cd.	$\text{UR} = \text{SR} \cdot \frac{cd}{ab}$	Remarks.

CHAPTER VII

CALIBRATION OF ELECTRICAL MEASURING INSTRUMENTS

Introduction.—The accurate measurement of current strength by means of indicating instruments is undoubtedly one of the most important factors in practical electrical testing. The author ventures to state that of the soft-iron types of indicating ammeters and voltmeters to be found in practical use, only a small percentage would be found under test to have a greater accuracy than 1 per cent. Of the other types of instruments, the mean accuracy of those working on the hot-wire principle is somewhat better than that of the soft-iron variety, both being superseded by the ¼ per cent. mean accuracy of the swinging-coil (D'Arsonval) type of ammeters and voltmeters.

The above figures are only approximate, but they serve to indicate the importance of frequent comparison of commercial measuring instruments with standards. Such a comparison is called a "calibration" or "standardisation." The inaccuracy of an instrument may be due to one or more of a variety of causes, the most frequent being those introduced in the original makers' calibration, in which the necessary train of processes:—calibration with a standard instrument (introducing errors of observation, magnetic errors, errors due to the production of heat in the instrument, etc.); plotting of the calibration curve and deduction therefrom of the scale (introducing errors of plotting, drawing, and observation again); and, finally, errors introduced in the actual "marking-off" of the scale by hand or dividing machine. It is the accuracy of the instrument at this stage which is indicated by the figures above. Other errors are introduced in instruments by their treatment in transit from one place to another, which may have the effect of altering their physical constants so that their indication with a given current strength is not the same as formerly. Finally, errors may be introduced in the manner of using an instrument. It must be remembered that the physical constants of an instrument will change with temperature, which generally means a change in deflection for a given current. The influence of temperature is particularly great in the case of voltmeters, a part or the whole of whose resistance is of copper; since a voltmeter is but a low-reading ammeter, it means that for any other temperature than normal the resistance is other than normal, so that with a given p.d., the current passing through it—and therefore the deflection—is also other than normal.

Magnetic errors are often introduced in soft-iron instruments in use, due to changes in the magnetic properties of the iron employed in the movement, and in swinging-coil instruments, due to changes in the strengths of the permanent magnets. Both types—particularly ammeters of the former type—may be influenced by the proximity of other magnetic apparatus, or by the positions of the connecting leads to their terminals. The influence of the latter may be greatly minimized by twisting the leads together so as to produce little or no resultant field. All outside magnetic influences can be entirely (or almost entirely) eliminated by providing the instrument with an iron case or its equivalent, which acts as a magnetic shield. It is now the general practice to provide such cases for all permanent-magnet instruments. With hot-wire instruments the most frequent errors are those due to temporary mechanical hysteresis of the thin wires and suspensions employed, which, together with changes in outside temperature, give rise to "changes of zero," necessitating the adjustment of the pointer to zero at the beginning of each test. These influences have also a somewhat similar effect to that of an alteration of strength of the permanent magnet in a D'Arsonval instrument, viz. a change of constant. Added to the above, all types are liable to errors caused by accident; this especially is the case with portable instruments.

Hence the necessity for frequent and accurate calibration.

Experiment No. K1.—Calibration of an Ammeter by comparison with a Standard Ammeter.

Introduction.—Standard current measuring appliances being generally of delicate construction and difficult to use, resort is frequently made in practice to sub-standards. Sub-standards for continuous current are generally instruments of the D'Arsonval type, which are calibrated from time to time by comparison with the standard appliance, and which may be relied upon in the mean time to conform to the last calibration curve with an accuracy of, say, about 1 per cent. Simultaneous readings are then taken of the sub-standard and the instrument under calibration, and the correct values of the current is obtained for each reading from the sub-standard calibration curve.

Diagram of Connections.—

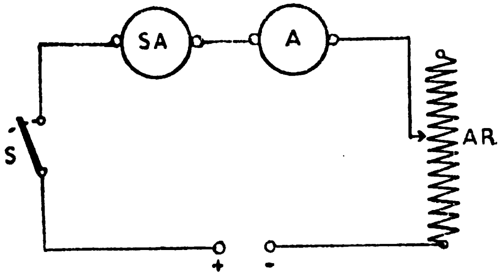

FIG. 35.

Apparatus required.—

SA = sub-standard ammeter with its calibration curve.
A = ammeter to be calibrated.
+ − = source of low E.M.F.
AR = adjustable resistance.
S = switch.

Method.—(1) Adjust the pointer of A to zero, and, if necessary, that of SA also. (NOTE.—Great care should be exercised in using SA, and the above adjustment of the pointer should be omitted if possible, it being a fact that if the instrument has just recently been in use, the pointer generally comes to rest somewhat above zero, and this should be considered before any adjustment is attempted). Ensure that the positive lead is connected to the + terminals of SA and A.

(2) Adjust AR for a large reading, say about 5 per cent. above the full scale reading (amps.) of A, and having done so, momentarily break circuit with S, and as the pointer of A swings to rest at the deflection, gently tap the glass faces of the two instruments. The former precaution ensures almost complete freedom from error due to magnetic hysteresis in the instruments, and the latter serves to greatly diminish errors due to mechanical imperfections of the movements, *e.g.*, pivot friction, etc. Note the readings on SA and A.

(3) Decrease the current by about 8 to 10 per cent. of the maximum by means of AR, momentarily break circuit, and after observing the precautions in (2) above, note the readings on SA and A simultaneously.

(4) Repeat (2) and (3) for gradually *decreasing* values of C, taking in all about 10 or 12 steps; note in each case the readings on SA and A simultaneously.

(NOTE.—The calibration should be made with changes of current in *one direction only, i.e.* continuously decreasing or increasing readings.)

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Readings on instruments.		**True amps.**	**Correction for A.**	**Remarks.**
SA	**A**			
				Instrument SA —— **Ammeter A (type, etc.) ——**

Plot a calibration curve for A, having readings on A for abscissæ and true amps. for ordinates. Or plot a curve having readings on A for abscissæ, and "corrections for A" as ordinates—

Results—

RECORD OF EXPERIMENT NO. K1.

Calibration of an Ammeter.

Ammeter No. 16360 N.C.S. Patent, reading up to 10 amps.
gravity control.

I.	II.	III.	IV.	V.
Readings on instruments.		True amps.	Correction for A.	Remarks.
SA	A			
10·1	10·0	10·0	None	Instrument SA.—Kelvin and White, sub-standard No.
8·6	8·45	8·5	Add 0·05	
7·09	7·05	7·0	Subtract 0·05	
5·57	5·5	5·5	None	Ammeter A (as above).
4·05	4·05	4·0	Subtract 0·05	Circuit momentarily broken; no hysteresis error.
2·52	2·5	2·5	None	
2·52	2·47	2·5		Increasing, circuit unbroken.
4.05	4·0	4·0		
5·57	5·47	5·5		
7·09	7·0	7·0		
8·6	8·45	8·5		
10·1	9·95	10·0		
				← Circuit broken.
10·1	10·0	10·0		Decreasing, circuit unbroken.
8·6	8·6	8·5		
7·09	7·15	7·0		
5·57	5·67	5·5		
4·05	4·15	4·0		
2·52	2·62	2·5		

The first curve is plotted in Fig. 36, and the last two in Fig. 37, in which the arrows indicate the curves for increasing and decreasing current respectively.

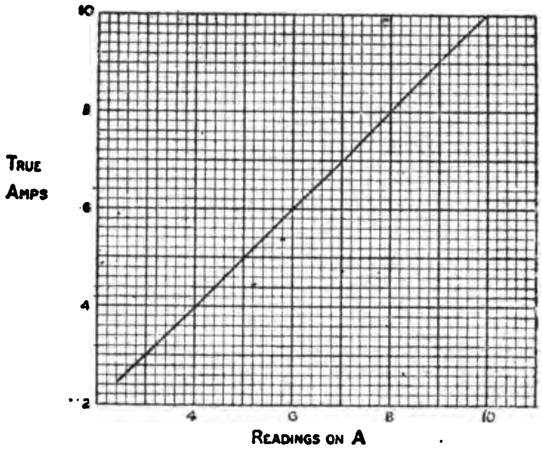

Fig. 36.

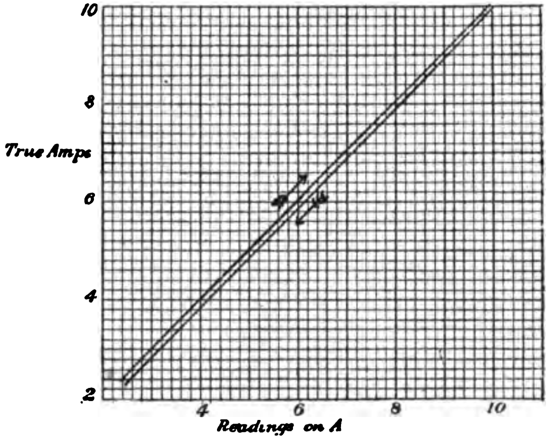

Fig. 37.

Experiment No. K2.—Calibration of a Voltmeter by comparison with a Standard Voltmeter.

Introduction.—Read carefully the introduction to this chapter.

In the calibration of a voltmeter further considerations than those mentioned in Experiment K1—the Calibration of an Ammeter—are necessary. From considerations of the method of using them, instruments may be broadly classified as of two types—

(*a*) Those for momentary testing only (this includes all such instruments as portables, cell testers, etc.).

(*b*) Those which are always in circuit (generally switchboard instruments). From considerations of the manner in which the magnetizing coils and resistance coils are wound, they may again be broadly classified as—

(i.) Those in which the magnetizing coils and resistance coils are of manganin wire, or of some other material having a negligible temperature coefficient.

(ii.) Those in which the resistance coils are of manganin or other similar material, but whose magnetizing coils are of copper wire.

Now, the effect of leaving an instrument continuously in circuit is to raise the temperature of the coils above that of their surroundings by an amount depending on the type, size, etc., of, and watts taken by, the instrument. The time taken by an instrument to "heat up" to a steady final temperature above that of the surrounding atmosphere varies considerably with the properties of the instrument enumerated above. In some tests made on two types of switchboard voltmeters having soft-iron movements and connected to the normal line voltage, the average times of a series of tests, taken by the instruments to assume a steady temperature, were 1 hour 30 minutes and 2 hours 15 minutes respectively. If the instrument to be calibrated belongs to class (*a*) above, practically no heating takes place in it when in use, and the process of calibration should be carried out to correspond as nearly as possible to the actual use of the instrument in practice, *i.e.* to prevent heating, the whole process of calibration should not occupy more than a few minutes, or, the instrument should be placed out of circuit for a short time after each reading. This method is not of such importance with instruments of the class (*a*) (i.) above, but is essential with instruments of the (*a*) (ii.) class. It is, however, advisable to employ it even in class (*a*) (i.) for the reason that although the actual resistance of the instruments may remain unaltered, there will be a change of temperature of the coil bobbins, movement, etc., which *may* affect the deflection by a perceptible amount if the instrument is kept long in circuit.

Instruments belonging to class (*b*) present difficulties in calibration. Since these instruments are continuously in circuit, their temperature is always higher than that of the surrounding atmosphere, and this temperature, as stated above, depends upon the voltage supplied to the terminals of the instrument. Also, apart from any alteration of resistance, the deflection may be altered by the resulting expansion of the mechanism of the instrument, and the amount of alteration will depend on the rise of temperature, *i.e.* on the effective value of the p.d. previously applied and the period of its application. This is the only consideration with instruments of class (*b*) (i.), and the author finds that for the majority of switchboard voltmeters of this type, the effect on the deflection of the pointer is so slight as to be negligible, and in a great many cases unreadable. Hence instruments of the class (*b*) (i.) may be calibrated as explained previously, *i.e.* without heating up, or they may be calibrated after having been in circuit for some time, both scales being found on comparison to be in the majority of cases identical. With instruments of the class (*b*) (ii.), there presents itself, in addition to the above, the effect of a rise of temperature on the copper magnetizing coil or coils.

The resistance of these coils will increase with a rise of temperature, and this has the effect of decreasing the current flowing, *i.e.* the ampere-turns, in the instrument for a given applied voltage. The consequence is, of course, a decreased deflection. The amount of this decrease, besides depending on the properties of the instrument previously mentioned, will for a given rise of temperature depend also on the ratio of copper to total resistance in the instrument, being greater for a large percentage of copper resistance. In the two types of instruments mentioned above, this ratio was one-fourth copper in both, and after both had been heated up by their normal voltage for three hours, the decrease in their reading at that pressure was found to be 2 per cent. and 1·5 per cent. respectively. The temperature coefficient of copper is 0·4 per cent. per degree C., so that the temperature coefficient of both instruments is $\frac{0·4}{4}$ per cent. = 0·1 per cent. per degree C. Hence the effective temperature rise in the first instrument was clearly $\frac{2}{0·1} = 20°$ C.; and in the second instrument $\frac{1·5}{0·1} = 15°$ C. under the above conditions. Had the instruments been previously run on a voltage other than normal, and then momentarily tested at their normal voltage, the decrease would, of course, be different to the above.

Two methods of calibration therefore present themselves here for instruments of the class (*b*) (ii.), viz.—

(1) Calibration to be made quickly to prevent heating up, and the known constants of the instrument subsequently applied as per above.

(2) Calibration to be made after the instrument has been heated up by the normal p.d. for a sufficient length of time to attain its maximum temperature.

Method (1) is that usually employed by manufacturers for the quick calibration of commercial instruments, the constants instanced above (which have been pre-determined for the class of instrument under calibration) being applied subsequently. As, however, this method requires an accurate knowledge of the heating constants of the instrument to be calibrated, it cannot generally be followed in the laboratory, and method (2) must be employed.

In considering method (2) it is necessary to remember that a voltmeter for switchboard use is seldom used at any but the bus-bar voltage, the maximum range of which is seldom greater than + or − 10 per cent. of normal p.d.

Also, on such occasions in which the instrument is required to indicate higher or lower p.d.'s than normal, the readings are momentary readings only, and the instrument is at the steady temperature attained after a continuous run at bus-bar voltage. Hence the most satisfactory method of calibrating such an instrument is to ensure that it has attained its working temperature, and then to calibrate it from the highest to the lowest point on the scale, taking a relatively large number of readings within the above limits (+ 10 per cent. to − 10 per cent.) of normal instrument reading. The experiment consists in calibrating a voltmeter by one of the methods enumerated in this introduction, the method being given for a switchboard voltmeter calibrated by method (2).

Diagram of Connections.—

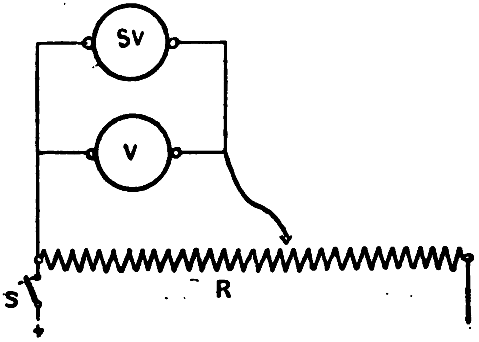

Fig. 38.

Apparatus required.—

SV = sub-standard voltmeter with its calibration curve.
V = voltmeter to be calibrated.
+ − = source of constant E.M.F. about 20 per cent. higher than normal.
R = high resistance provided with a movable contact.
S = switch.

Method.—(1) Adjust the pointers on SV and V to zero (see (1) in the previous experiment).

(2) Close S and adjust the movable contact of R for about the normal voltage as measured by SV. Disconnect SV and leave V in circuit to be heated up by the normal voltage for at least half an hour. In the majority of instruments the temperature of V rises rapidly at first, and attains a temperature only a few degrees lower than its final temperature after about half an hour.

(3) Place SV in circuit again and calibrate V from a reading about 20 per cent. above normal to as low as possible, taking readings more frequently in the vicinity of normal voltage, and observing with great care the precautions explained in the method of the preceding experiment. Take in all 10 or 12 simultaneous readings on SV and V.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Reading on instruments.		True volts.	Correction for V.	Remarks.
SV	V			
				Instrument, SV. Voltmeter, V —— Previous treatment of V —— Room temperature ——

Plot a Calibration Curve for V having readings on V for abscissæ and True Volts for ordinates. Or, plot a curve having readings on V for abscissæ, and "Corrections for V" as ordinates.

Results— RECORD OF EXPERIMENT NO. K2.

Calibration of a Voltmeter.

I.	II.	III.	IV.	V.
Readings on Instruments.		True Volts.	Correction for V.	Remarks.
SV	V			
75	80	Same as column I.	—	Instrument SV.—Kelvin and White, standard voltmeter. Instrument V.—Crompton Gravity type.
81	83		2 high	
88	88		—	
98	97		1 low	
100	100		—	
112	112		—	
118	116·5		1·5 low	
125	125		—	
134	134		—	
141	141		—	
158	158		—	
178	178		—	
193	192		1 low	
207	207		—	
212	210		2 low	
216	216		—	
226	225		1 low	
228	228		—	

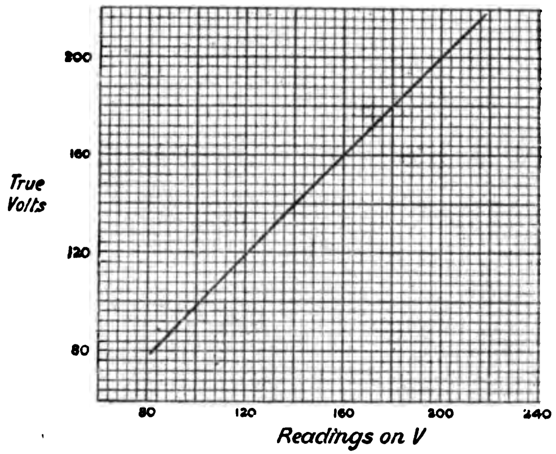

FIG. 39.

Experiment K3.—Calibration of a Wattmeter by comparison with a Standard Ammeter and a Standard Voltmeter.

Introduction.—A wattmeter is an instrument which measures the product of amps. and volts supplied to it; it is essentially a combined ammeter and voltmeter, the deflection of the pointer being dependent on the interaction of the two portions upon one another. A wattmeter should read accurately the power supplied to a circuit when either the current or the pressure, or both, vary in value within their respective limits stated on the instrument.

The calibration here described is that of a wattmeter under each of the above conditions by comparison with a standard or sub-standard ammeter and voltmeter placed in its circuit, the supply being direct current. There will therefore be three separate calibrations—

A.—With constant voltage and variable current.
B.— „ variable „ „ constant „
C.— „ „ „ „ variable „

In common with ammeters and voltmeters, wattmeters are liable to many errors, and the remarks made in the introduction to this chapter and to portions A and B apply also here; also, the precaution there enumerated should be rigorously followed if the calibration is to be of any service.

Diagram of Connections.—

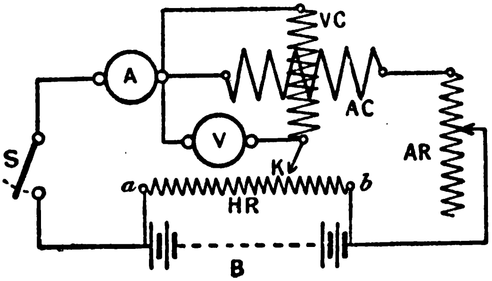

Fig. 40.

Apparatus required.—

VC, AC = voltmeter and ammeter coils of wattmeter.
A = standard or sub-standard ammeter.
V = „ „ „ „ voltmeter.
AR = adjustable resistance (say water resistance).
HR, K = high resistance and adjustable contact key to obtain various voltages.
B = source of steady supply.
S = main switch.

Method.—A. Constant Potential.—(1) Carefully adjust the pointers of all the instruments to zero. Insert all AR and close S. Adjust AR for a convenient current as indicated on A, then move K over HR towards B until V indicates the voltage required. Gently tap the dials of all instruments whilst making these adjustments (to overcome frictional errors), and note the readings on V, A, and the wattmeter.

(2) Adjust AR for a slightly increased current, then again adjust the voltage to its correct value, and after gently tapping all the dials, note the values of E, C, and watts W.

(3) Repeat (2) for currents up to the maximum capacity of the instruments, taking about ten readings in all and carefully noting the corresponding values of E, C, and W.

(4) Repeat for decreasing values of C.

B. Constant Current.—(1) Carefully adjust AR until the maximum current for the instrument is indicated on A. Move K towards A so as to get a small voltage indicated on V. Observe the usual precautions and take the values of E, C, and watts.

(2) Repeat for voltages up to the maximum for the instrument, taking about ten readings in all.

(3) Repeat for decreasing voltages.

C.—Variable Current and Voltage.—(1) Adjust AR and the position of K for small values of C and E, and after tapping, note these values and the reading on W.

(2) Take increasing values of C and E up to the maximum values for the instrument, taking about ten readings and noting all the values of C, E, and W.

(3) Repeat for decreasing values of C and E.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Reading on V.	True volts, E.	Reading on A.	True amps. C.	True watts, E × C.	Wattmeter reading, W.	Remarks.
						C increasing.
						A. Constant voltage.
						C decreasing.
						E increasing.
						B. Constant current.
						E decreasing.
						E and C increasing.
						C. Variable E and C.
						E and C decreasing.

Plot on three large diagrams curves between true watts and wattmeter readings for both increasing and decreasing values in tests A, B, and C respectively. Draw the average curve on each.

Plot the three average curves obtained on one diagram, and if they do not coincide, draw their average curve. From this final curve construct a table giving the error of the instrument at readings 10, 20, etc., up to 100 per cent. of full scale reading.

Results—

RECORD OF EXPERIMENT NO. K3.

Calibration of a Wattmeter.

I. Reading on V.	II. True volts, E.	III. Reading on A.	IV. True amps., C.	V. True watts, E × C.	VI. Watt-meter reading, W.	VII. Remarks.
110	Same as I.	2·13	Same as III.	234·5	222	A. Constant voltage. C increasing.
110		2·6		286	273	
110		3·1		341	330	
110		3·54		389	370	
110		3·97		436·5	422	
110		4·45		489	476	
110		4·84		532	520	
110		6·2		582	570	
109·8	Same as I.	5	Same as III.	549	540	B. Constant current. E decreasing.
102·5		5		512·5	505	
92·8		5		463·5	455	
81·8		5		409	405	
72		5		360	352	
61·5		5		307	302	
48·8		5		244·5	240	
36·3		5		181·5	176	
20·2		5		101	100	
113·5	Same as I.	5	Same as III.	567·5	560	C. Variable E and C. E and C decreasing.
105·7		4·5		471·5	455	
95·8		4		383	373	
84		3·6		302·5	294	
74·4		3·2		238	230	
65		2·8		182	176	
51		2·5		127·4	123	
30		2		61·4	60	

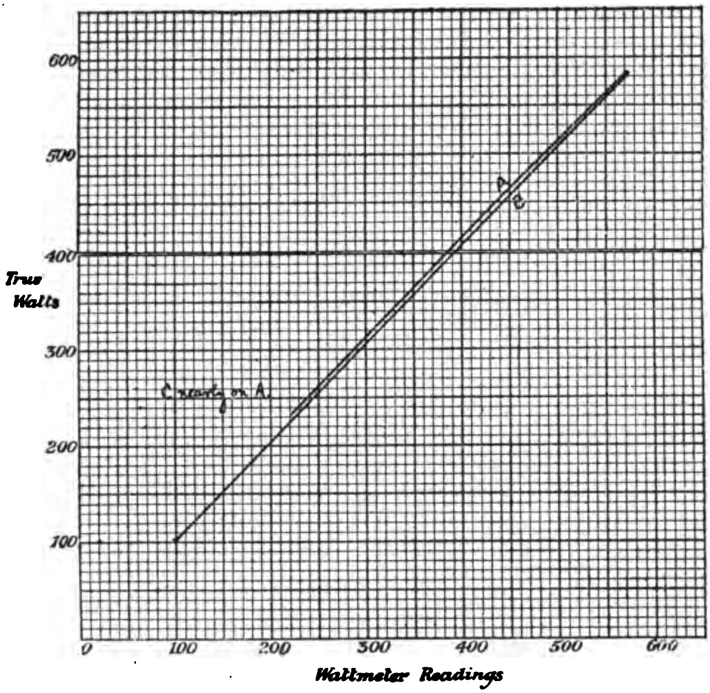

FIG. 41.

Experiment K4.—Test of an Electricity Meter.

Introduction.—Electricity meters are instruments which measure the amount of energy delivered to a circuit; they differ from a wattmeter in that whereas the latter measure the product of C and E, meters measure the product of C, E, and time. They are therefore provided with an ammeter and voltmeter portion, and mechanism to record the product of these two quantities and time. It will immediately be evident, however, that when energy is supplied at constant pressure, an instrument measuring and adding up successive products of current and time will give indications representing products of C, E, and time.

Such meters are classified as—

(A) Quantity, coulomb, or ampère-hour meters.

The former are classified as—

(B) Energy, watt-hour, or integrating wattmeters.

Meters may be, again, classified according to their principle of action, as (1) Motor meters; (2) clock meters; (3) electrolytic meters.

Class A may be constructed on either principle 1, 2, or 3, whilst those of class B are confined to types 1 and 2, since those instruments in class 3 depend for their action upon the chemical action of the current which is proportional to C × time. The instrument tested should be first fully classified as above, and connected up accordingly.

The diagram of connections and method here given are for an instrument belonging to class B1—a motor meter measuring products of C, E, and time, the best known meters of which type are the Ferranti,[*] Elihu Thomson, Shallenberger,[†] Hookham,[*] and Westinghouse[†] meters. In each of these meters the indications on the recording dial are proportional to the revolutions of the rotating portion, so that for a constant potential supply the revolutions per hour of the rotor should be exactly proportional to C. This, then, suggests the main test of the instrument, viz. to test whether the speed of revolution of the rotor is proportional to C. This is accomplished by counting the revolutions per minute *n* of the rotating part for various constant values of *c* and plotting these against C, when the resulting curve should be a straight line. The other portion of the test will be to find whether the instrument records correctly for, say, an hour, and to find the least current necessary to rotate the armature. All currents below this latter will, of course, be supplied to the customer free of charge.

The wording of the method below, although generally applicable to the above instruments, applies particularly to the Elihu Thomson meter.

Diagram of Connections.—

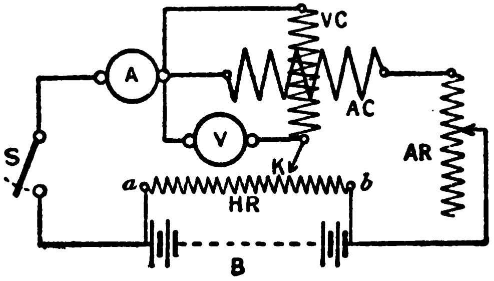

Fig. 42.

Apparatus required.—As for calibration of a wattmeter. Also a stop-clock (minutes and seconds fingers).

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[*] These meters are really amp-hour meters since they are not provided with a voltmeter coil.

[†] For alternating current only.

Method.—(1) Connect up the wattmeter as shown, and, in addition, connect up the compensating or compounding coil, if one is provided on the meter. The function of such a coil is to produce a very slight torque, just sufficient to overcome resistances due to friction of pivots, etc., so that the motor commences to rotate and record the slightest current through the main coil. Make a white mark on the rotor either with chalk or by gumming a small piece of stamp paper on to it; this is to enable the counting of the revolutions of the armature.

(2) Break the main circuit by means of AR and close S. Adjust the position of K on AR so that V and VC receive the normal voltage of the meter. This voltage is to be kept constant throughout.

(3) Insert all the resistance of AR, and gradually decrease it, *i.e.* increase C until the motor *just* commences to rotate. Repeat this two or three times, and take the average value of the current so found. All values of C below this value are not recorded by the meter, since they produce no rotation of the armature.

(4) Repeat (3) with the compensating coil disconnected, and compare the new starting current with that required when the compensating coil is in use. The new current is that required in the ammeter coils to overcome the friction of the armature, and is the maximum current which the customer could receive without charge if no compensating coils were provided. Re-connect the compensating coils.

(5) Adjust AR so that the full current stated on the meter is indicated on A; the rotor will now be revolving at a good speed. Count the number of revolutions in one minute; note the current C and the speed n_1. In performing the experiment, care must be taken that the speed of the motor is unaffected by external influences, *e.g.* air draughts, touching with the hand, etc.

(6) Repeat (5) for decreasing values of steady current, say 0·75, 0·5, and 0·25 of the maximum, in each case verifying the voltage on V and VC, and noting corresponding values of C and n.

NOTE.—The above readings should not include the starting and stopping of the motor, but should only be taken over periods when all the factors, C, E, and speed, are constant.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
Voltage on V and VC, E.	**Current on A and AC, C.**	**Revolutions per minute, *n*.**	**Remarks.**
			Starting current— **With compensating coil ___** **Without compensating coil ___**

Plot a curve showing the relation between *c* and *n* with values of *c* as abscissæ and of *n* as ordinates.

State what facts are shown by this curve; also find from it the total number of revolutions of the armature per B.O.T. unit.

Finally, make a test of the accuracy of the instrument by passing through it, say, 1000 watts for one hour, when the instrument should indicate one B.O.T. unit having passed through it. It is not possible to perform this task to any great accuracy, since meters are generally not graduated to less than 0·1 of a B.O.T. unit; readings can, however, be made to a greater accuracy than this by watching the complete rotation of a marked tooth on the wheel attached to pointer moving over the units dial.

Compare the actual reading of the instrument with the B.O.T.'s supplied to it.

Results— RECORD OF EXPERIMENT No. K4.

Test of an Electricity Meter.

I.	II.	III.	III.
Voltage on V and VC, E.	Current on A and AC, C.	Revolutions per minute. *n.*	Remarks.
100	2·2	20	Resistance of Ammeter portion = 0·08 ohm ∴ watts lost at 5 *a* = 2 watts Resistance of voltmeter portion = 2400 ohms ∴ watts lost at 100 volt = 4·5 watts ∴ Total loss = 6·5 watts.
100	3·9	28·5	
100	5·0	39	
100	6·0	50	
100	7·2	60	
110	2·1	17	
110	3·5	30	
110	5·0	46	

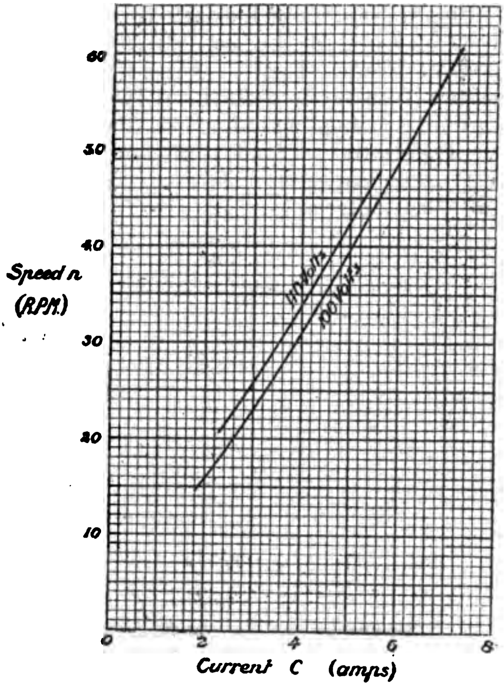

FIG. 43.

From the above curves it is found that at 100 volts and 5 amps. the error of the meter in favour of the customer was 2·84 per cent.

Experiment No. K5.—Calibration of a Mirror Galvanometer.

Introduction.—The experiment is to determine the "sensitiveness" of a mirror galvanometer for given conditions. The "sensitiveness" or "figure of merit" of a reflecting galvanometer is expressed as the current in ampères required to produce unit deflection on the scale. With a given galvanometer this current will depend upon two conditions—

(1) The length of each division of the scale, *i.e.* whether in millimeters or some other unit; and

(2) The distance of the scale from the mirror.

In galvanometers provided with a controlling magnet a third condition occurs—

(3) The position of the controlling magnet.

It follows, therefore, that, in expressing the figure of merit for any galvanometer, each of the above conditions should be stated.

The current might be obtained either by measuring the current in the main circuit by a low-reading sub-standard, and calculating the value of the current in the shunted galvanometer, or by placing a large known resistance in series with the galvanometer and calculating the value of the current supplied to the circuit by a cell of known E.M.F. The latter method is the one employed here, the E.M.F. of the cell being measured beforehand on the potentiometer.*

Diagram of Connections.—

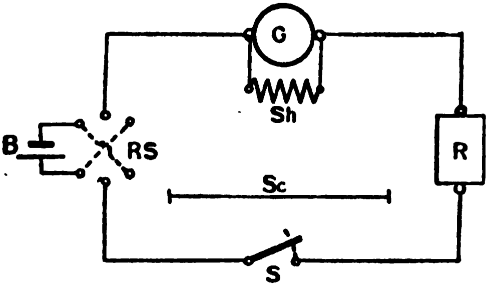

Fig. 44.

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* See chapter on "The Potentiometer."

Apparatus required.—
G = galvanometer to be calibrated.
Sh = shunt for G.
Sc = scale for G.
B = cell of constant E.M.F.
RS = reversing switch.
R = external resistance box.
S = switch or key.

Method.—(1) Measure the E.M.F. of the cell B by means of the potentiometer; call this E.

(2) Set the scale so that the "spot" of light reads zero on Sc.; place in a low-resistance shunt Sh, and the maximum resistance in R, and close S. So arrange the values of Sh and R to obtain the maximum deflection possible on the scale, making the total resistance of the circuit as large as possible.

(3) Close S, and note the deflection to right and left by reversing with RS. Note the values of R, Sh, and G combined, and the internal resistance of B (if appreciable compared with R).*

(4) Repeat (2) for gradually decreasing deflection, *i.e.* increasing the resistance in R, noting carefully in each case the two deflections and the corresponding values of R and Sh.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
External resistance, R ohms.	Resistance of B, G and Sh.	Total resistance in circuit.	Deflections.			E.M.F. of cell B = E.	Remarks.
			Left.	Right.	Aver.		
							G = ____ cms. from scale. B = ____ G = ____ Sh = ____ $\frac{G \times Sh}{G+Sh}$ = ____ Galvo. = ____

Draw a curve showing the relation between total resistance and average deflection, plotting values of R for ordinates.

To find the figure of merit from this curve choose any point, and note the values of R_{total} and deflection *d*.

---

* See Tables in Appendix.

Then, the total current in the circuit $= \dfrac{E}{R_{total}}$

the "shunting value" of S*h* on G $= \dfrac{Sh + G}{Sh}$

$\therefore$ the current through G $= \dfrac{E \,.\, Sh}{R_{total} \times (Sh + G)}$

and this gives a deflection *d*, so that the

$$\text{Figure of merit} = \frac{E \,.\, Sh}{R_{total}(Sh + G) \,.\, d}$$

State any assumptions made in the above, and what objections would be raised to the use of the figure of merit so obtained with a much larger deflection than the maximum employed in the determination.

Results—

Record of Experiment No. K5.

Calibration of a Mirror Galvanometer.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
External resistance, R ohms.	Resistance of B, G, and S*h*.	Total resistance in circuit.	Deflections.			E.M.F. of cell, B = E.	Remarks.
			Left.	Right.	Aver.		
5,000	323	5,323	340	320	330	218	B = negligible. Scale in millimetre divisions. $\dfrac{G \,.\, Sh}{G + Sh} = 323$ ohms. G = 72 cms. from scale. Galvo. = D'Arsonval "Midget." Galvo. No. 8071 = 94·4 ohms.
6,000	„	6,323	290	270	280	„	
7,000	„	7,323	250	230	240	„	
8,000	„	8,323	215	210	213	„	
9,000	„	9,323	190	190	190	„	
10,000	„	10,323	175	173	174	„	

Figures of merit from above—

Shunting value of S*h* = 30.

Calculations give—

$4{\cdot}07 \times 10^{-8}$
$4{\cdot}13 \times 10^{-8}$
$4{\cdot}11 \times 10^{-8}$
$4{\cdot}13 \times 10^{-8}$
$4{\cdot}1 \times 10^{-8}$
$4{\cdot}1 \times 10^{-8}$

Average = $4{\cdot}1 \times 10^{-8}$ amps. per division.

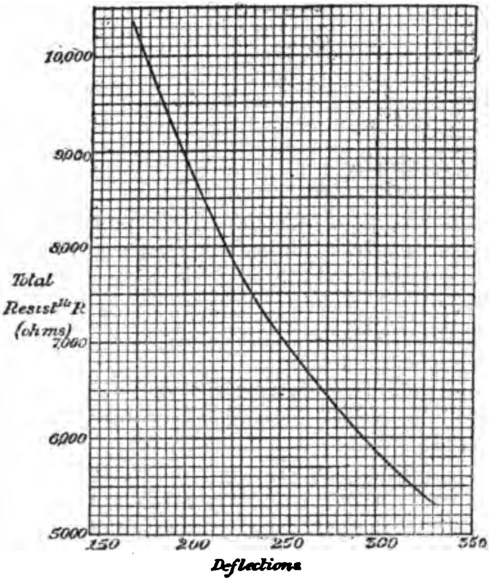


FIG. 45.

Experiment No. K6.—Calibration of a Metre-bridge Wire (Gray's Method).

Introduction.—The uses of the stretched wire of a metre bridge or potentiometer in the laboratory are numerous. In using it the assumption made is that length represents resistance, *i.e.* the wire has the same resistance per cm. throughout its length. The following is Gray's modification of the Carey-Foster method of testing the uniformity of or calibrating a bridge wire over its length. The modification consists in making all the important connections permanent; those of a temporary character only being confined to the galvanometer circuit where they have no disturbing influence,

Diagram of Connections.—

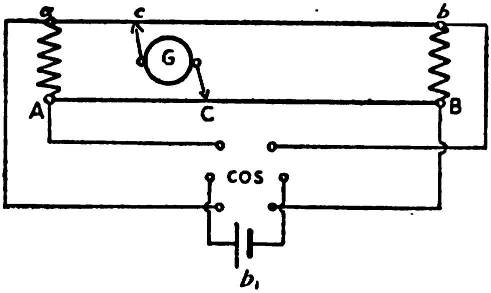


FIG. 46.

Apparatus required.—

ab = wire to be calibrated.
AB = second bridge wire of same resistance as wire *ab*.
r, *r* = two equal low resistances, *a*A, *b*B (each about one-twentieth of that of wire *ab*).
b_1 = battery.
cos = change-over switch.
G = galvanometer.
c, C = tapping contacts on wires *ab* and AB.

Method.—(1) To verify the equality of resistances *r*, *r*, join b_1 across AB, and obtain balancing points for *c* and C on wires *ab* and AB. Now place b_1 on *ab*, and if $r = r$, no deflection will occur.

(2) Connect up as above, and switch b_1 on A and *b*; place contact *c* on *a*, and move C along AB for a balance on G. Note the lengths *ac* and AC.

(3) Change over b_1 on to *a* and B, leave C undisturbed, and move *c* along *ab* for a balance. Note the lengths *ac* and AC.

(4) Again change over to A and *b*, leave *c* undisturbed, and find a balancing point for C on AB; noting the lengths *ac* and AC.

(5) Repeat (3) and (4) until *c* arrives nearly up to *b*; noting in all cases the lengths *ac* and AC.

By this means both wires *ab* and AB will have been divided up into a number of short lengths, each having a resistance 2*r*.*

---

* This is only true if AB = *ab*. If they are not equal, it can be shown (*e.g.* see Gray's "Absolute Measurements," vol. i. p. 348) that the resistance of each step is equal to $2r\frac{AB + r}{ab + r}$.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Reading on bridge, $ab = ac$.	Differences.	Resistance of *ac*.	Reading on bridge, AB = AC.	Differences.	Remarks.
					Length and resistance of *ab* ——

To find the values in Column III., the value of r, or of the wire *ab*, will have to be known. If the value of r is known, the column will read $2r$, $4r$, $6r$, etc. If r is not known, it may be found after the test from the number of steps, each of value $2r$, which have been made on *ab*.

Plot a curve showing the relation between lengths *ac* and resistance, taking lengths on the abscissæ.

Results—

RECORD OF EXPERIMENT No. K6.

Calibration of a Metre Bridge Wire (Gray's Method).

I.	II.	III.	IV.	V.	VI.
Reading on bridge, $ab = ac$.	Differences.	Resistance of *ac*.	Reading on bridge, AB = AC.	Differences.	Remarks.
0	—	—	7·45	7·45	ab = 100 cms.
14·75	14·75	0·2635	22·75	14·7	= 1·687 ohms.
29·7	14·95	0·527	38·45	15·7	
45·15	15·45	0·7905	54·45	16·0	
60·8	15·65	1·054	70·7	16·25	
76·8	16·0	1·3175	87·4	16·7	
93·3	16·5	1·581			

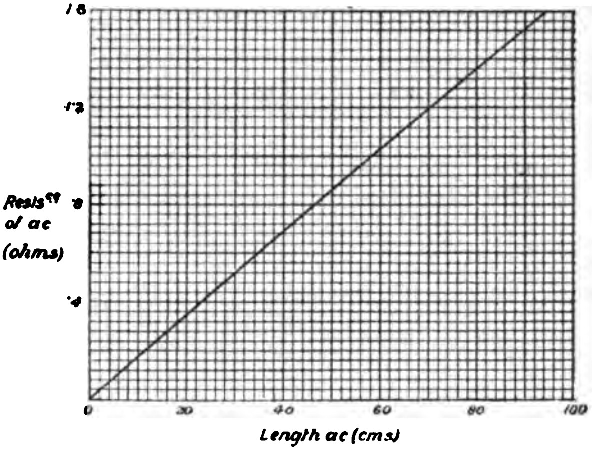


FIG. 47.

CHAPTER VIII

MISCELLANEOUS EXPERIMENTS

Experiment No. M1.—Variation of Resistance with Dimensions and Material.

Introduction.—The experiment is to determine the relation between resistance and length, and resistance and cross-sectional area, of wires of different materials.

Diagram of Connections.—As for any suitable method of measuring resistance.

Apparatus required.—

(*a*) Wires of the same material, of the same cross-sectional area, but of different lengths.

(*b*) Wires of the same material, of the same lengths, but of different diameters (*i.e.* areas).

(*c*) Wires of the same length and area, but of different materials.

Apparatus for a suitable method of measuring resistance.

Method.—(1) Measure the resistance of each of the wires in (*a*) above, noting the material, the area of cross-section A in sq. cms., the length of the wire L in cms., and the resistance R in ohms.

(2) Measure the resistance of each wire in (*b*) above, noting the material, L in cms., A in sq. cms., and R in ohms.

(3) Measure the resistance of each wire in (*c*) above, noting the material and R of each wire, L and A, and the temperature of the room in each case.

Results.—Tabulate your results thus—

(1.)

I.	II.	III.	IV.	V.
Material.	**A sq. cms.**	**L cms.**	**R ohms.**	**Remarks.**
				Room temperature = ——° C.

Plot a curve having values of R for ordinates, and of L for abscissæ.

(2.)

I.	II.	III.	IV.	V.
Material.	L cms.	A sq. cms.	R ohms.	Remarks.
				Room temperature = ——° C.

Note that the product of L and A is constant, or that R varies as $\frac{1}{A}$, and hence plot a curve having values of R for ordinates, and of $\frac{1}{A}$ for abscissæ.

(3.)

I.	II.	III.	IV.	V.
L cms.	A sq. cms.	Material.	R ohms.	Remarks.
				Room temperature = ——° C.

Note from curve (1) above, $R \propto L$, and from curve (2), that $R \propto \frac{1}{A}$ for the same material. Therefore—

$$R = \frac{L}{A} \times \text{a constant}$$

and since L and A are measured in cms. and sq. cms. respectively, the constant is the resistance between the two opposite faces of a centimetre cube of the material. This is the specific resistance of the material at the particular temperature, and is usually denoted by ρ.

So that for any material—

$$R = \rho\frac{L}{A}$$

where ρ is the specific resistance of the material.

The values of ρ for the different materials measured are directly derivable from (3)—

$$\text{since } R = \rho\frac{L}{A}$$

$$\therefore \rho = R\frac{A}{L}$$

Results—

RECORD OF EXPERIMENT No. M1.

TABLE I.

I.	II.	III.	IV.	V.
Material.	A sq. cms.	L cms.	R ohms.	Remarks.
German silver 30 S.W.G.	$d = 0{\cdot}0315$ cm. $A = 0{\cdot}000779$ sq. cm.	200 100 75 50	5·77 ohms 2·89 2·26 1·45	Temp. 16° C.

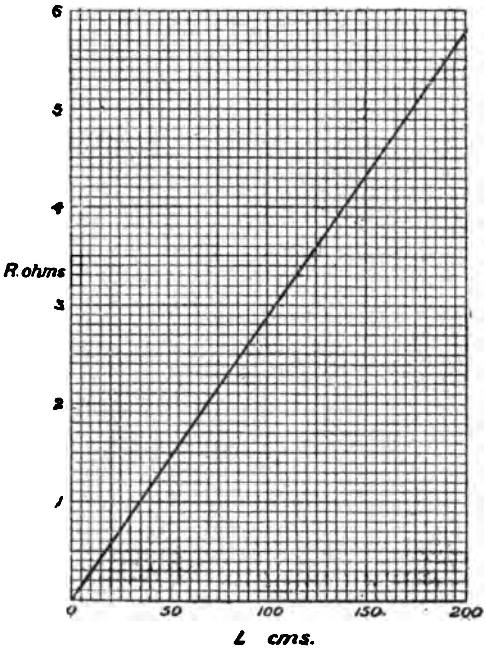


FIG. 48.

TABLE II.

I.	II.	III.	IV.	V.	VI.
Material.	L cms.	A sq. cms.	R ohms.	$\frac{1}{A}$	Remarks.
German silver	100	30 S.W.G. 0·000779	2·89 ohms	1283	Temp. 16° C.
	„	26 „ 0·00164	1·37 „	609	
	„	22 „ 0·00397	0·57 „	252	
	„	18 „ 0·0117	0·192 „	855	

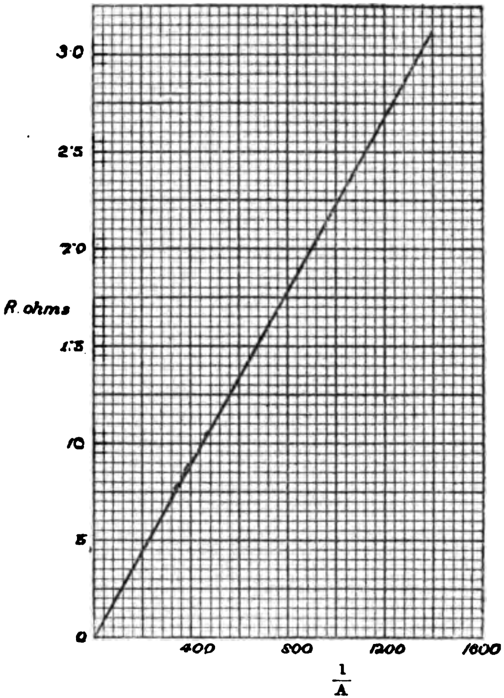


FIG. 49.

TABLE III.

I.	II.	III.	IV.	V.
L cms.	A sq. cms.	Material.	R ohms.	Remarks.
100	30 S.W.G. 0·000779	Cu (annealed)	0·22	Temp. 16° C.
„	„ sq. cm.	German silver	2·89	
„	„	Aluminium	4·0	
„	„	Iron (annealed)	1·38	
„	„	Tin	1·8	

Values of ρ calculated from formula—

$$\rho = R\frac{A}{L}$$

Copper = $1·71 \times 10^{-6}$ ohms per cm. cube.
German silver = $22·5 \times 10^{-6}$ „ „
Aluminium = $3·12 \times 10^{-6}$ „ „
Iron (annealed) = $10·52 \times 10^{-6}$ „ „
Tin = $14·0 \times 10^{-6}$ „ „

Experiment No. M2.—Laws of Combination of Resistances.

Introduction.—When a number of resistances are connected in series, the total resistance of the circuit is their sum. For a number of resistances connected in parallel, the total resistance is found indirectly. It is obvious that the "conducting power" of the circuit will be the sum of the "conducting powers" of the respective resistances, and since the conducting power of the circuit of R ohms is represented by the reciprocal of R, *i.e.* $\frac{1}{R}$, the total conducting power of a number of resistances, R_1, R_2, etc., in parallel, is represented by $\frac{1}{R_1} + \frac{1}{R_2} +$ etc.

$$\text{Hence } \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \text{etc.}$$

The experiment is to verify the above laws.

Diagram of Connections.—As for any suitable method of measuring resistance.

Apparatus required.—A number of resistances of different values capable of being connected in series or parallel.

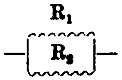
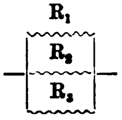
Apparatus for a suitable method of measuring resistance.

Method.—(1) Measure each of the resistances, R_1, R_2, etc., separately.

(2) Connect any two in series, and measure their combined resistance; then any three, and then any four, measuring their combined resistance in each case.

(3) Connect any two in parallel, then any three, and so on, measuring the combined resistance in each case.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
R_1.	R_2.	R_3.	R_4.	Circuit.	Measured resistance.	Calculated resistance.	Remarks.
				  etc.			

NOTE.—The expression for the resistance of a parallel circuit is best left in the form given above, viz.—

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \text{etc.}$$

If worked out for R directly, for three or more resistances, the expression becomes unnecessarily complicated; for example, for three resistances, R_1, R_2, and R_3 in parallel—

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

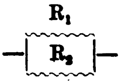
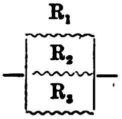
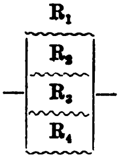
$$\frac{1}{R} = \frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1R_2R_3}$$

$$\therefore R = \frac{R_1R_2R_3}{R_2R_3 + R_1R_3 + R_1R_2}$$

Hence the reason for employing the original formula above, giving $\frac{1}{R}$.

Results—

RECORD OF EXPERIMENT NO. M2.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
R_1	R_2	R_3	R_4	Circuit.	Measured resistance.	Calculated resistance.	Remarks.
ohms	ohms	ohms	ohms		ohms	ohms	
10	10	—	—		5·0	5·0	
10	10	10	—		3·35	3·3	
10	5	15	20		2·42	2·4	

Experiment No. M3.—Variation of Resistance with Temperature of Different Materials.

Introduction.—The variation of the resistance of conductors with temperature is of great practical importance. The majority of conductors increase in resistance with temperature; they have a "positive coefficient." Those substances whose resistance decreases with a rise in temperature are said to have a "negative coefficient." The coefficient being the ratio of the alteration in resistance per degree C. to the resistance at 0° C. The experiment is to determine the value of this coefficient for different metals.

Diagram of Connections.—As for any accurate method of measuring resistance.

Apparatus required.—A number of coils of wire of different metals, preferably bare wire wound on perforated insulation bobbins. Apparatus for raising the temperature of the coils, preferably an inner vessel containing oil, and in which the coils are placed, surrounded by an outer vessel containing water heated by a bunsen burner. An accurate thermometer.

Apparatus as above for the accurate measurement of resistance.

Method.—(1) Immerse the coils in the oil bath, stir the oil well for uniform temperature T° C. throughout, and accurately measure the resistance of each coil. Note temperature T° C. by an accurate thermometer and resistance R_T ohms of each coil.

(2) Heat the water in the outer vessel with the bunsen burner continuously, and when the temperature of the oil and coils has been raised about 5° C., carefully measure the resistance of each coil in turn. Great care should be taken to keep the oil well stirred, so as to obtain the exact uniform temperature throughout, and since the measurement of a number of resistances takes time during which the temperature is continually rising, the reading on the thermometer should be taken at the moment of balance in each case. Note the values of T_1 and R_{T_1} in each case.

(3) Repeat (2) for successive rises of about 5° C., up to a temperature of about 100° C., observing carefully the precautions in (2) in each case.

(4) Repeat all measurements when the apparatus is cooling down.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Material ___		Material ___		Material ___		Remarks.
Tempera-ture ° C.	R	Tempera-ture ° C.	R	Tempera-ture ° C.	R	
						Heating.
						Cooling.

Let R_0 = the resistance of a coil at 0° C.
R_T = „ „ the coil at T° C.

$$\text{Then } R_T = R_0 (1 + \propto T)$$

where $\propto$ is the "temperature coefficient" of the material.

Plot curves for each case above, showing the relation of resistance and temperature, taking values of resistance as ordinates, and of temperature as abscissæ. From the above expression the curves are straight lines, cutting the axis of R at a point R_0. Choose the average line between the two curves plotted for heating and cooling in each case, and by taking any point on it together with the point R_0, find $\propto$ for the material.

Results—

RECORD OF EXPERIMENT NO. M3.

I.	II.	III.	IV.	V.	VI.	VII.
Material, copper.		Material, iron.		Material, German silver.		Remarks.
Temperature ° C.	R ohms.	Temperature ° C.	R ohms.	Temperature ° C.	R ohms.	
15	10·6	15·0	10·8	15	10	Heating.
34	11·5	36	11·8	30	10·1	
55	12·2	57	12·7	50	10·16	
73	13·0	74	13·5	70	10·25	
92	13·8	93	14·6	90	10·3	

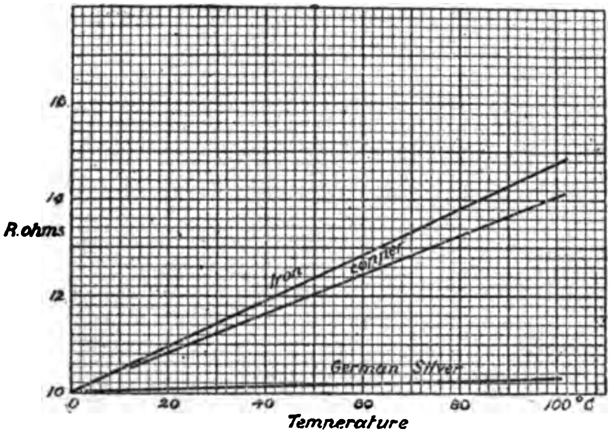


FIG. 50.

Values of $\propto$ from above—

Iron = 0·0048.
Copper = 0·0041.
German silver = 0·00034.

Experiment No. M4.—Resistance Test on a Storage Cell (Potentiometer Method).

Introduction.—The object of the experiment is to ascertain the internal resistance of a storage cell or accumulator, and how it is affected by the extent to which the plates are immersed in the acid of the cell. The resistance of the cell is made up of a number of factors:—

(*a*) Terminal and plate resistance.
(*b*) Contact resistance of plates and electrolyte.
(*c*) Resistance of electrolyte itself.

The factors (*b*) and (*c*) will obviously depend upon (amongst other things) the extent to which the plates are immersed in the electrolyte.

The method adopted to measure the resistance of the cell is essentially that employed in experiment R14, with the addition that the terminal E.M.F. of the cell is measured not by a voltmeter directly, but by balancing it against the drop of potential along a potentiometer wire supplied with a constant current.

Diagram of Connections.—

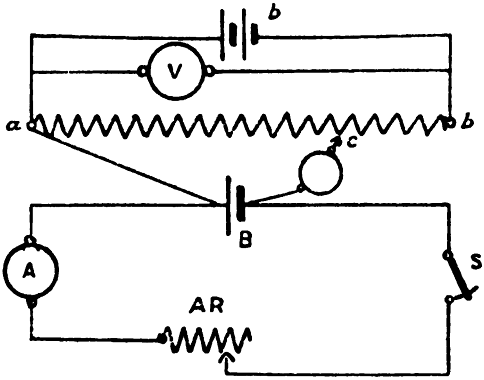


FIG. 51.

Apparatus required.—

B = cell to be tested.
b = battery supplying constant current.
A = accurate ammeter.
AR = adjustable resistance.
S = switch.
G = galvanometer.
ab = potentiometer wire.
V = voltmeter.

Method.—(1) Obtain a fully charged cell whose plates are in good condition (*i.e.* free from buckles, etc.), and after emptying completely of acid, connect up as shown. Then fill the cell with its acid until one-quarter of their depth is immersed, and shake well to get rid of any bubbles adhering to the plate surfaces.

(2) With S open, obtain a balance on *ab*, and find the open circuit E.M.F. of B by calculation; thus—

$$\text{E.M.F. of B} = \frac{\text{resistance } ac}{\text{resistance } ab} \times \text{V}$$

$$\text{or } \frac{\textbf{length ac}}{\textbf{length ab}} \times \textbf{V}$$

(3) Adjust AR for a small current, and close S. Obtain a balance on *ab*, and note the current C indicated on A, and the terminal E.M.F. of B.

(4) Repeat (3) for increasing values of C, noting in all cases the corresponding values of C, and length *ac*.

(5) Repeat for the plates immersed to half, three-quarter, and their whole depth in the acid.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Potentiometer E.M.F. = V.	Potentiometer length, *ab*.	Balancing length, *ac*.	Cell, $E = \frac{ac}{ab} \cdot V$	Drop in cell = l_v	Current, C.	Resistance of cell = $\frac{l_v}{C}$	Remarks.

Plot curves showing how the E.M.F. of the cell B drops with increasing current C for the different condition, quarter, half, three-quarter, and complete immersion of the plates.

State how the internal resistance of the cell is affected by the extent to which the plates are immersed in the electrolyte.

Results—

RECORD OF EXPERIMENT NO. M4.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Potentiometer E.M.F. = V.	Potentiometer length, *ab*.	Balancing length, *ac*.	Cell, $E = \frac{ac}{ab} \cdot V$	Drop in cell $= l_r$	Current, C.	Resistance of cell $= \frac{l_r}{C}$	Remarks.
						ohms	
4·26	400	214	2·285	—	0		¼ full.
„	„	195·6	2·080	0·205	1·01	0·203	
„	„	170	1·810	0·475	2·1	0·226	
„	„	159	1·692	0·593	3·28	0·181	
						Average R = 0·207	
4·26	400	215	2·285	—	0		Full.
„	„	209	2·225	0·060	1·3	0·0462	
„	„	203·4	2·160	0·125	2·26	0·0553	
„	„	200·4	2·130	0·155	2·9	0·0518	
						Average R = 0·0511	

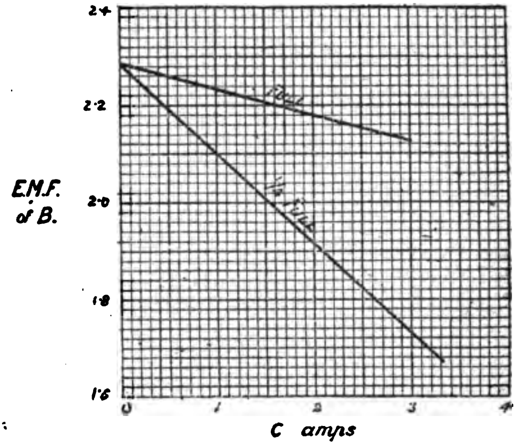


FIG. 52.

Experiment No. M5.—Variation of Resistance of an Incandescent Lamp with Voltage applied to it.

Introduction.—The resistance of the carbon filament of a glow or incandescent lamp is found to be greater in the cold state than when hot, so that carbon has a "negative temperature coefficient."

A simple method of measuring the resistance of the hot filament is to measure the current passing and the potential drop in the filament, and to find its resistance by Ohm's law directly. Although the temperature of the filament in each case is not known, the relation between C and R, and between R cold and R at normal working current (R hot), is obtained.

Diagram of Connections.—

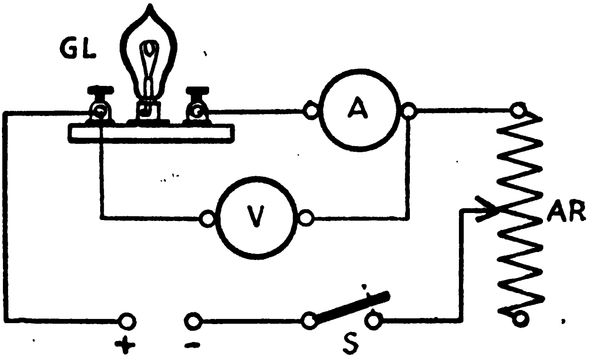


Fig. 53.

Apparatus required.—

GL = glow lamp.
A = low reading ammeter, 0–1 amp.
V = voltmeter, 0–25 per cent. above normal voltage.
AR = high adjustable resistance.
+ – = lighting mains.
S = switch.

Method.—(1) Find the resistance of the lamp in the cold state by means of any accurate method, *e.g.* the post-office box method.

(2) Adjust AR for a very small current through the lamp as indicated on A. Note C indicated on A, and E indicated on V.

(3) Increase C, and note the new values of C and E.

(4) Repeat (3) up to about 1·1 normal voltage (if possible), noting corresponding values of C and E.

(5) Repeat the observations for decreasing currents.

Let R_L = resistance of the lamp GL,
R_A = „ „ ammeter A,

$$\text{Then } R_L = \frac{E}{C} - R_A$$

since the ammeter is in series with GL, and E is measured over both.

R_A is usually negligible compared with R_L, so that the expression for R_L stands—

$$R_L = \frac{E}{C}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Lamp GL.	Increasing C.			Decreasing C.			Remarks.
	C.	E.	$R_L = \frac{E}{C} - R_A$	C.	E.	$R_L = \frac{E}{C} - R_A$	

Plot curves showing the relation between R_L and C for both increasing and decreasing currents, plotting values of R as ordinates, and of C as abscissæ.

Note.—An intentional error frequently made in the laboratory is to regard the resistance of voltmeters as so great that their shunting effect on a circuit is negligible. The error involved in such a case depends on the resistance of the voltmeter and that of the circuit shunted by it; the smaller the ratio of the resistance of the voltmeter to that of the circuit so shunted, the greater will be the error.

In the above experiment the case can be considered from the following:—

Diagram of Connections.—

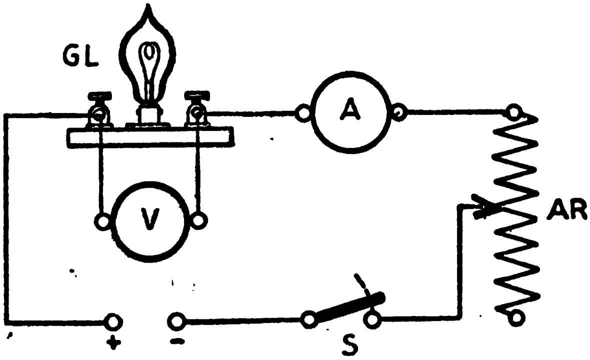


FIG. 54.

Let C_V = current through the voltmeter,
R_V = resistance of the voltmeter,
E = reading on V,

$$\text{Then } C_V = \frac{E}{R_V}$$

Also if C = main current indicated on A,
C_L = current through the lamp GL,

$$\text{Then } C_L = C - \frac{E}{R_V}$$

and if R_L = resistance of lamp GL,

$$R_L = \frac{E}{C - \frac{E}{R_V}}$$

So that the results would be tabulated as follows:—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Lamp GL.	Increasing C.				Decreasing C.			
	C	E	$C_L = C - \frac{E}{R_V}$	$R_L = \frac{E}{C - \frac{E}{R_V}}$	C	E	$C_L = C - \frac{E}{R_V}$	$R_L = \frac{E}{C - \frac{E}{R_V}}$

And curves plotted for respective values of C_L and R_L so calculated.

If R_V be neglected, the error involved is clearly equal to—

$$\left\{\frac{R_L - \frac{R_V \cdot R_L}{R_V + R_L}}{R_L}\right\} \times 100 \text{ per cent.}$$

Additional Note.—In this and some subsequent experiments it is required to increase the supply voltage 5 or 10 per cent. above normal. This can be complied with by using apparatus to be tested whose normal voltage is 10 per cent. less than that of the school supply. This, however, will generally be impossible, so that where the supply voltage is never increased above that of the lamp, the following convenient method is resorted to. Obtain secondary cells sufficient for the extra voltage and large enough to supply the full current demanded from the supply, and connect them up in series with the supply voltage, *i.e.* negative end of cells to positive terminal of supply; thus—

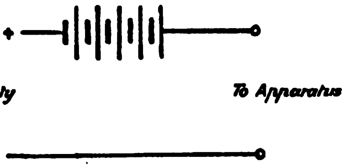


FIG. 55.

The voltage of the cells is thus *added* to that of the supply.

Results—

RECORD OF EXPERIMENT No. M5.

TABLE I.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Lamp GL.	Increasing C.			Decreasing C.			Remarks.
	C	E	$R = \frac{E}{C} - R_A$	C	E	$R = \frac{E}{C} - R_A$	
Royal Ediswan, 110 volts, 16 C.P.	0·22	47	213·6 − 0·0615	0·585	107	183 − 0·0615	
	0·27	56	207·8	0·545	101	200	
	0·34	68	200	0·495	93	188	
	0·39	75	192·5	0·42	79	188	
	0·44	84	191	0·38	75	197·5	
	0·50	94	188	0·31	63·5	205	
	0·55	102	185·5	0·25	53	212	
	0·59	107	181·5	0·22	48	218	

TABLE II.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Lamp GL.	Increasing C.				Decreasing C.			
	C	E	$C_L = C - \frac{E}{R_V}$	$R_L = \frac{E}{C - \frac{E}{R_V}}$	C	E	$C_L = C - \frac{E}{R_V}$	$R_L = \frac{E}{C - \frac{E}{R_V}}$
Royal Ediswan, 110 volts, 16 C.P.	0·22	48	0·2146	221·8	0·59	107	0·577	186
	0·395	77	0·3864	199	0·47	87	0·460	189
	0·46	87	0·4502	193	0·36	71	0·352	201·8
	0·59	107	0·5769	186	0·23	49	0·224	218·2

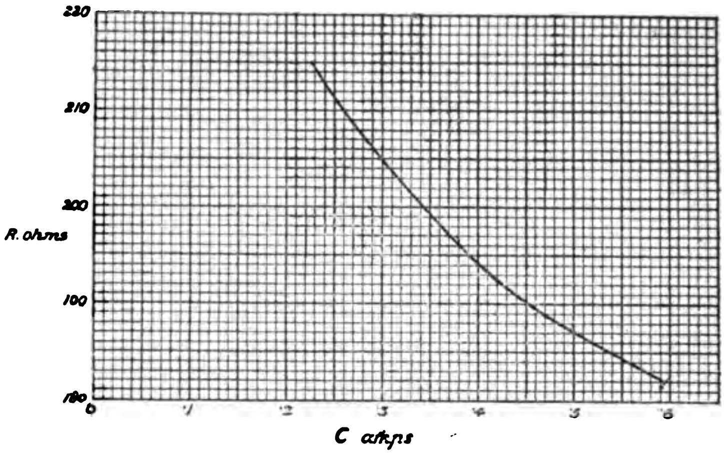


FIG. 56.

Experiment No. M6.—Complete Electrical Tests of Incandescent, Carbon, Tantatum, and Osmium Lamps.

Introduction.—The experiment is to find how the resistance of the filaments of carbon and other glow-lamps varies with voltage applied to them, and indirectly, with temperature.

Diagram of Connections.—

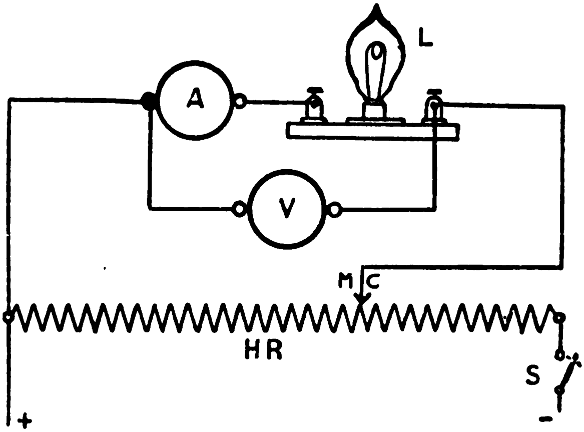


FIG. 57.

Apparatus required.—
L = lamp to be tested.
A = low-reading ammeter.
V = voltmeter.
MC = movable contacts.
HR = high resistance across supply mains (at least 50 ohms).
+ − = source of E.M.F.

Method.—(1) Connect up as above, placing V across L and A.*

(2) Place the lamp in the stand, adjust the movable contact, MC, so as to obtain a small reading on V. Note simultaneous values of C and V, as indicated on A and V respectively.

(3) Repeat (2) for gradually increasing values of V up to, but not above, a voltage 10 per cent. in excess of normal lamp voltage.† Note C and V in each case, and incidentally the appearance of the lamp filament, whether glowing or not.

(4) Repeat (2) and (3) for lamps having filaments of different materials (tantalum, etc.).

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Description of lamp tested.	Volts, V.	Current, C.	Resistance of filament $R_L = \frac{V}{C}$	Watts taken by lamp = VC.	Remarks.
					(Appearance of filament.)

Plot curves showing the relation between the following for each lamp tested:—

(i.) Current and volts,
(ii.) Resistance and volts,
(iii.) Watts and volts.

Plot values of C, R, and watts as ordinates and of volts as abscissæ. From the curves so obtained write down the resistance of current and watts taken by each lamp at its normal voltage. Assuming the candle-power stated on the lamp bulb, find the so-called "efficiency" ‡ of each lamp, *i.e.* watts per C.P., and compare these one with the other. State what conclusions you draw from the appearance of each curve.

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* See Experiment M5.

† See "Additional Note," Experiment No. M5.

‡ See paragraph (*i*) in Experiment M7.

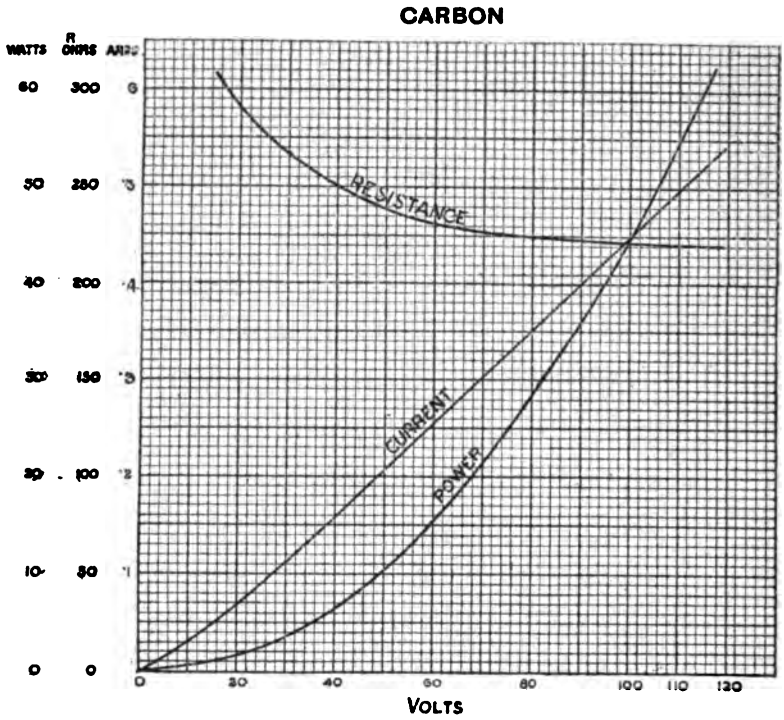

Fig. 58.

Results— RECORD OF EXPERIMENT No. M6.

I.	II.	III.	IV.	V.	VI.
Description of lamp tested.	**Volts, V.**	**Current, C.**	**Resistance of filament $= R = \frac{V}{C}$**	**Watts taken by lamp = VC.**	**Remarks.**
Royal Ediswan, carbon filament, 110 volts, 16 C.P. lamp.	17·5	0·057	307	1·0	Filament just glows. Filament cold = 440 ohms.
	29·78	0·112	266	3·33	
	34·2	0·134	253	4·52	
	48	0·20	240	9·6	
	59·2	0·256	231	15·15	
	73·6	0·326	225·5	24·0	
	85	0·38	223·5	32·3	
	94·5	0·425	222·5	40·1	
	100·3	0·452	222·5	45·4	
	105	0·475	221	49·8	
	108·8	0·493	220·5	53·6	
	110·1	0·4985	221	54·75	
	111·5	0·506	220·5	56·3	
	114·5	0·52	220·5	59·5	
	118	0·536	220·5	63·15	
Tantalum (Siemens), 110 volts, 25 C.P.	15	0·88	169	1·32	Filament visible at 10 volts, glows at 13 volts.
	24	0·123	195	2·95	
	35·4	0·16	221	5·65	
	47·6	0·20	238	9·52	
	59·2	0·234	253	13·85	
	70·8	0·266	266	18·83	
	85·8	0·306	280·5	26·25	
	97	0·334	290·5	32·4	
	104	0·35	297	36·4	
	107·5	0·36	299	38·7	
	110	0·366	301	40·25	
	112·5	0·375	300	42·2	
	115·3	0·38	303·5	43·8	
	116·3	0·383	304	44·5	
	118·5	0·387	306·5	45·85	
Osmium lamp (G.E.C°.), 55 volts, 25 C.P.	10·92	0·07	156	0·764	Glows at 13 volts. To compare the properties of this 55-volt lamp with the preceding 110-volt
	14·72	0·085	173	1·25	
	19·5	0·103	189·2	2	
	24·2	0·121	200	2·93	
	31·8	0·143	223	4·55	

Record of Experiment No. M6.—*continued.*

I.	II.	III.	IV.	V.	VI.
Description of lamp tested.	**Volts, V.**	**Current, C.**	**Resistance of filament $= R = \frac{V}{C}$**	**Watts taken by lamp = VC.**	**Remarks.**
Osmium lamp (G.E.C°.), 55 volts, 25 C.P.	41·6	0·169	246	7·02	lamp, all the values of V have been doubled, and the values of C have been halved. This, of course, gives the resistance of a 110-volt lamp as four times that of the 55-volt of same C.P.
	49	0·188	261	9·2	
	53	0·197	269	10·44	
	59	0·211	280	12·44	
	65·8	0·226	291	14·9	
	68·8	0·238	289	16·37	
	76	0·248	306	18·7	
	85	0·267	316	22·7	
	98	0·29	338	28·4	
	106·6	0·308	346	32·8	
	113	0·32	353	36·1	
	121·2	0·336	361	40·8	

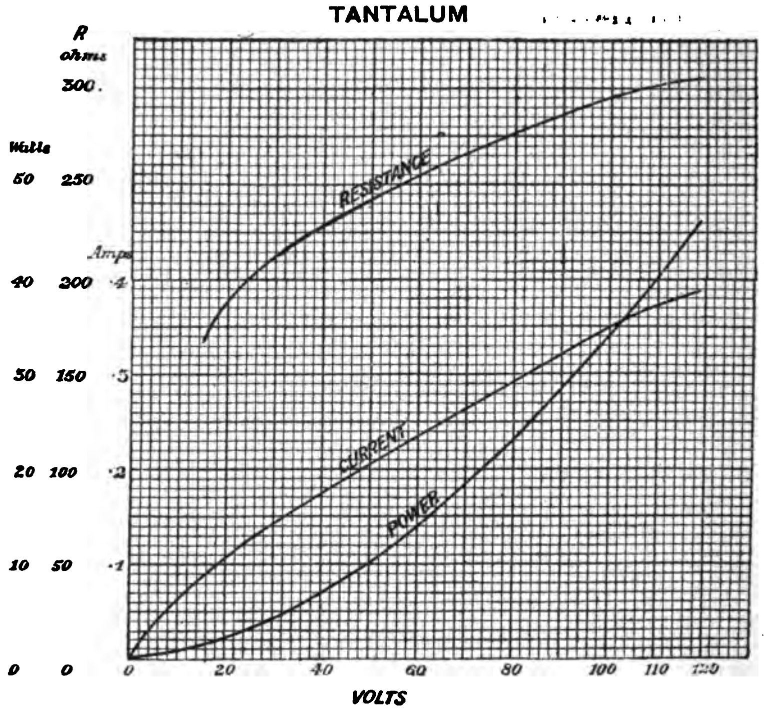

Fig. 59.

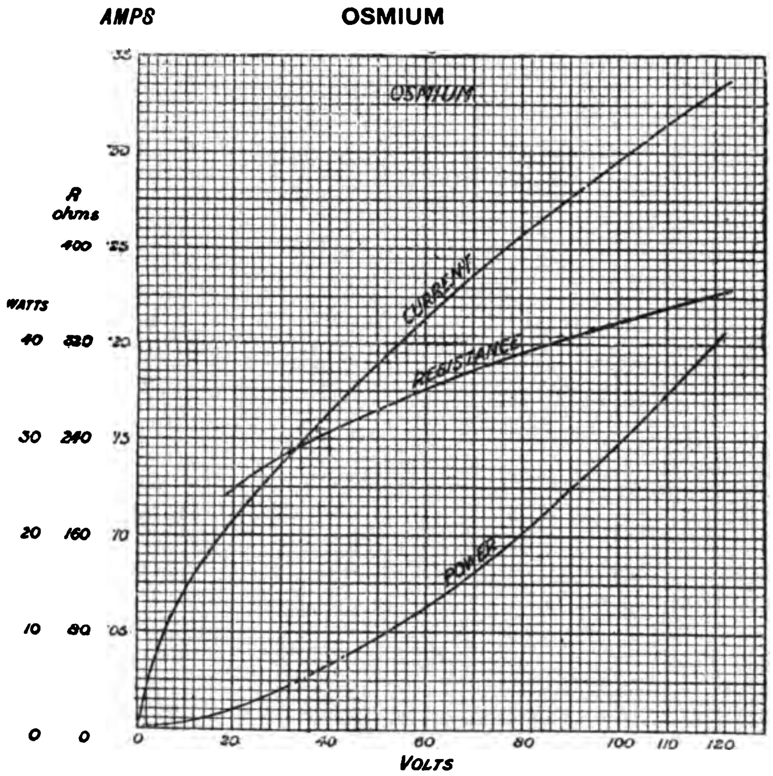

FIG. 60.

Experiment No. M7.—Behaviour of an Arc-Lamp on Continuous Circuit.

Introduction.—The experiment is to investigate the variation of current and voltage taken by an arc-lamp supplied by constant voltage mains.

Diagram of Connections.—

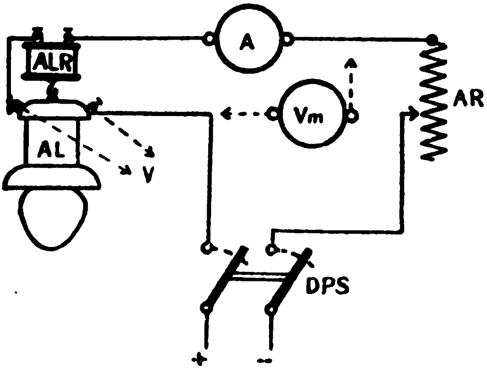

Fig. 61.

Apparatus required.—

AL = arc-lamp.
ALR = arc-lamp resistance.
A = accurate dead-beat ammeter.
V = „ „ „ voltmeter across lamp.
V*m* = „ „ „ „ „ mains.
+ − = supply mains.
AR = adjustable resistance.
DPS = Double pole switch.
A watch.

Method.—(1) Weigh each carbon separately.

(2) Connect up as above, close DPS, and verify the polarity of the arc.* Let lamp burn for at least 30 minutes, so as to attain normal running conditions.

(3) Arrange AR to be continuously varied so as to maintain constant the normal circuit voltage for which the lamp is intended, as indicated by V*m*.

(4) With V*m* indicating normal lamp voltage, take simultaneous readings of V and A, noting the time on the watch.

(5) Repeat (3) every half minute for 30 minutes or so, taking readings immediately after AR has been adjusted to give normal running voltage.

(6) Weigh each carbon when sufficiently cool.

---

* The top carbon is generally positive, its end being in the form of a crater. The polarity can be tested by switching on for a few seconds; when switched off the + carbon takes the longer time to cool.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Time.	Time from beginning.	Volts on mains, V*m*.	Volts on lamp terminals, V.	Current by A, C.	Remarks.
h. m.					

Plot the following curves on the same diagram:—

(i.) Volts on mains and time from beginning,
(ii.) Volts on lamp and time from beginning,
(iii.) Current through lamp and time from beginning,

taking time on the abscissæ in each case.

State generally what you conclude from the curves.

Draw horizontal average-lines for all three quantities; note that average lamp-watts = average V × aver. C; and that aver. total watts = aver. V*m* × aver. C.

From these curves determine the following:—

(*a*) normal main voltage,
(*b*) aver. volts on lamps,
(*c*) aver. current through lamp,
(*d*) aver. watts taken by lamp,
(*e*) aver. total watts taken by lamp and its resistance,
(*f*) aver. apparent ohmic resistance of lamp $= \frac{b}{c}$,
(*g*) resistance of ALR in ohms $= \frac{a-b}{c}$,
(*h*) the ratio of $\frac{\text{aver. watts by lamp}}{\text{aver. total watts}}$.

(*i*) Also find the "efficiency" of the arc lamp, *i.e.* the watts per candle-power (a better term would be the "inefficiency" of the lamp, the "efficiency" obviously being represented, not by watts per C.P., but by C.P. watt).

Also state the rate of consumption of each carbon in grams per hour, and from this find the number of hours one pair of carbons will last under the above conditions of constant voltage.

Results—

Record of Experiment No. M7.

II.	III.	IV.	V.	VI.
Time from beginning.	Volts on mains, V_m.	Volts on lamp, V.	Current by A, C.	Remarks.
Every half minute	110 volts constant throughout	99	5·4	Two open inverted arc lamps in series. From curve plotted we get the following:— (*a*) Total volts = 110 volts. (*b*) Aver. volts on lamp = 97·7 volts. (*c*) Aver. amps. on lamp = 5·29 amps. (*d*) Aver. watts = 517. (*e*) Aver. total watts = 582·5. (*f*) Aver. apparent ohmic resistance = 18·46 ohms. (*g*) Resistance in ALR = 2·32 ohms. (*h*) $\frac{\text{Aver. watts by lamp}}{\text{Aver. total watts}} = 0·8885.$
		97	5·2	
		97·5	5·2	
		97	5·3	
		97·5	5·4	
		98	5·4	
		98	5·3	
		98	5·3	
		98	5·4	
		97·5	5·3	
		97	5·5	
		97·5	5·3	
		97	5·4	
		97	5·35	
		97	5·4	
		98	5·3	
		98	5·2	
		97·5	5·3	
		98	5·2	
		98·5	5·4	
		98	5·5	
		98	5·2	
		98·5	5·3	
		98	5·25	
		98	5·25	
		99	5·4	
		98	5·3	
		97	5·2	
		98	5·2	
		98	5·2	
		99	5·1	
		99	5·1	
		97	5·2	
		98	5·3	
		98	5·3	

RECORD OF EXPERIMENT NO. M7.—*continued.*

II.	III.	IV.	V.	VI.
Time from beginning.	Volts on mains, V*m*.	Volts on lamp, V.	Current by A, C.	Remarks.
		98	5·2	
		98	5·1	
		97·5	5·2	
		99	5·5	
		97·5	5·3	
		97·5	5·3	
		98	5·4	
		97·5	5·35	
		97·5	5·4	
		98	5·2	
		98	5·3	
		98	5·3	
		97	5·25	
		97	5·3	
		98·5	5·1	
		97	5·3	
		99	5·3	
		97	5·3	
		98	5·25	

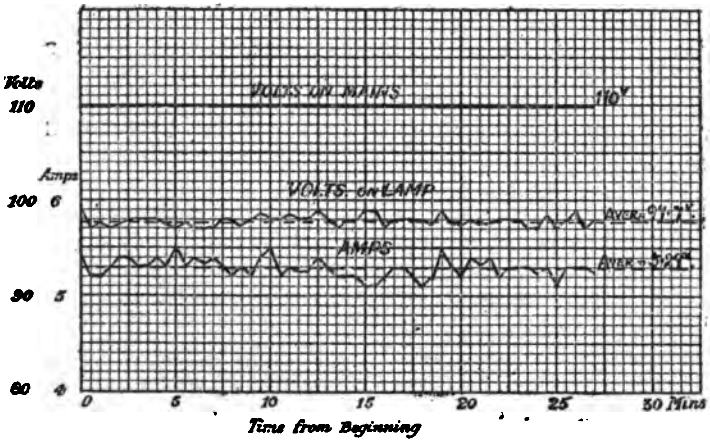

FIG. 62.

Experiment No. M8.

Photometric Tests on a Glow or Incandescent Lamp.

Introduction.—The experiment is to determine the manner in which the horizontal candle-power of a glow lamp varies with voltage applied to it. The C.P. is measured by comparison with a source of known C.P., preferably having the same colour of light.

Diagram of Connections.—

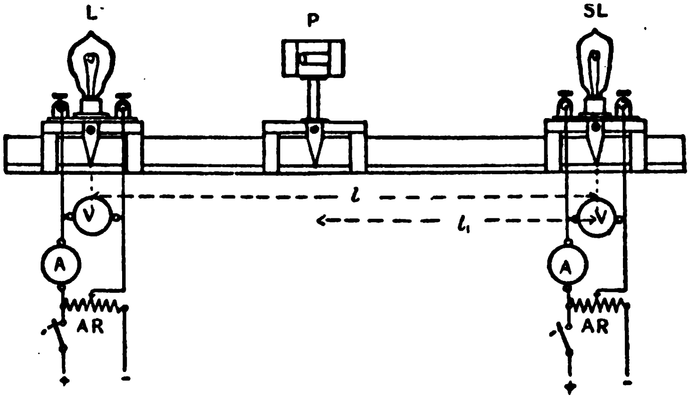

FIG. 63.

Apparatus required.—

L = lamp to be tested.
P = photometer and bench.
SL = standard lamp, *i.e.* either a standard source, or preferably a glow lamp whose C.P. at a particular voltage—at or about normal—is known accurately.
A = ammeter reading to one ampere.
V = voltmeter reading to 5 per cent. or 10 per cent. above normal voltage of L.
AR = high adjustable resistance.
+ − = source of E.M.F. up to 5 per cent. or 10 per cent. above normal voltage of L.

Method.—(1) Make the distance *l* some convenient length, say 100 or 200 cms. Fix L and SL in these positions permanently throughout the experiment.

Connect up L as shown, and SL so that the voltage at its terminals, as given by V_{SL}, is such as to give a known C.P. on SL. This voltage is to be maintained exactly the same and constant during each determination.

(2) Adjust AR until L just glimmers. Move P along the scale until a position is found such that on reversing P (if capable of reversal) the spot on the screen just disappears. Do this two or three times, and finally place P in the average position thus found. Measure the distance l, and note it and the readings on A and V.

(3) Increase V by 5 or 10 volts by adjusting AR, and after verifying the volts on SL, find the new position of P, repeating the precautions stated in (2). Note l_1, A, and V.

(4) Repeat (3) for increasing values of V up to about 10 per cent. below normal voltage, from which point readings should be taken every one or two volts up to about 10 per cent. above normal voltage of L.* Note in each case the values of l_1, A, and V.

The intensity of illumination from a source of light diminishes as the square of the distance from that source, so that

If L = C.P. of lamp L,
SL = C.P. of standard lamp,
l and l_1 = as above,

Then, when a balance has been obtained on P—

$$\frac{L}{(l-l_1)} = \frac{SL}{l_1^2}$$

$$\text{whence } L = SL\,\frac{(l-l_1)^2}{l_1^2}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
A, amps.	V, volts.	R ohms (hot) $= \frac{V}{A}$	Watts = AV.	Distance, l.	Distance, l_1 (mean).	C.P. of SL.	C.P. of L.	Watts per C.P. $= \frac{\text{watts}}{\text{C.P.}}$	Cost per C.P. per hour for power.

Column X. is calculated from any assumed price of power per B.O.T. (say 4*d.* to 6*d.*), and is for power only.

---

* See "Additional Note," Experiment No. M4.

From the results so obtained, plot the following curves to a common ordinate line of C.P. of L:—

(1) L and V.
(2) L and A.
(3) L and watts.
(4) L and watts per C.P.
(5) L and cost per C.P. per hour.

Given that—

$$\text{C.P.} = \text{K}\,.\,\text{V}^{n}$$
$$\text{and C.P.} = \text{K}_1\,.\,\text{A}^{n_1}$$

find the values of the constants K, K_1, n and n_1.

State the conclusions you draw from these and the other curves.

Results—

RECORD OF EXPERIMENT NO. M8.

(Price of current, 4*d.* per unit.)

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
A, amps.	V, volts.	R ohms (hot) $=\frac{V}{A}$	Watts = AV.	Distance, *l*.	Distance, l_1 (mean).	C.P. of SL.	C.P. of L.	Watts per C.P. $=\frac{\text{watts}}{\text{C.P.}}$	Cost per C.P. per hour for power.
		watts		cms.					
0·112	30	268		200	No balance				
0·198	50	252		„					
0·225	60	248		„					
0·32	75	234	24	„	148	16	2·0	12	0·048
0·40	90	225	36	„	128	16	5·2	6·92	0·0277
0·45	100	222	45	„	109	16	11·1	4·05	0·0162
0·475	105	221	49·8	„	105	16	13·2	3·77	0·0151
0·49	108	221	52·9	„	101·5	16	15·1	3·5	0·014
0·498	110	221	54·8	„	98·5	16	17	3·23	0·0129
0·506	111·5	221	56·4	„	97·0	16	18·1	3·12	0·0125
0·518	114	220	59	„	94·2	16	19 9	2·97	0·0119

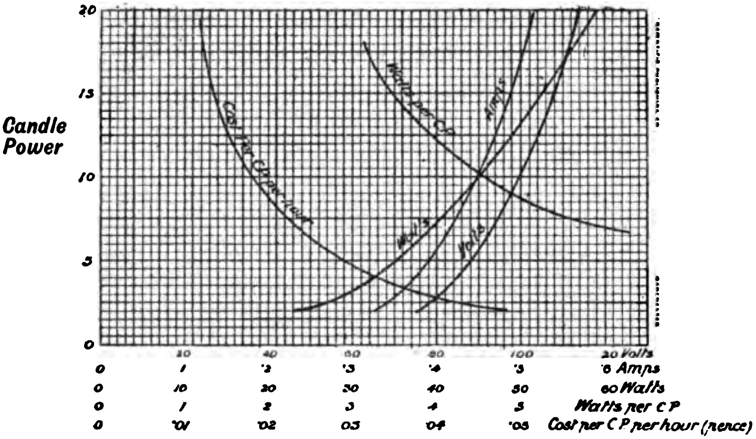

FIG. 64.

Experiment No. M9.—Photometric Test of an Arc Lamp.

Introduction.—The purpose of this experiment is to determine the distribution of light around an arc light, and from this to find the "commercial efficiency" (watts supplied to the whole lamp per C.P.), and the "nett optical efficiency" (watts supplied to the arc only per C.P.). It will thus be necessary to make the following measurements:—

C.P. in all directions;

Current consumed by the lamp;

Total volts supplied to the lamp and its resistance, and the volts across the arc itself.

Steps should be taken to ensure that the total volts supplied to the lamp can be kept constant throughout the test; for this purpose the source of supply should, if possible, be a battery of accumulators. When the lamp is so fed, an idea of the variation of current and volts across the arc itself has already been obtained from a previous experiment.* Since the exact relationship of the two voltages is of importance, they should be measured by the same voltmeter, which can be accomplished by the use of a two-way switch, when one voltage can be measured immediately after the other.

In the measurement of the C.P. of the arc numerous difficulties present themselves. It will be noticed, for instance, that the arc rotates around the edge of the crater in the positive carbon, so that the light emitted by the arc on an external fixed surface alternates in intensity. For this reason, as well as for those found in the previous experiment already referred to, a number of rapid measurements of the candle-power will have to be made, and the average of these taken as the C.P. in that particular direction. To obtain the C.P. over a large angle on the vertical plane, the light along those inclinations has to be projected along the axis of the photometer bench. To accomplish this, one or other of the following methods has to be resorted to:—

---

* "Behaviour of an Arc Lamp on Continuous Circuit."

(A) The centre of the arc can be placed on a line with the photometer and standard source of light, and the various angles obtained by tilting the arc.

(B) The lamp can be suspended from a pulley in the ceiling, and by adjusting its height the light at any angle can be reflected by a mirror along the axis of the bench.

Method A involves the use of a special apparatus for tilting the lamp, and containing a dial for measuring the tilt, and arrangements so that the centre of the arc can be adjusted on the axis of the photometer and standard light. Against its use may be urged the fact that after tilting through angles of more than 60°, difficulties are encountered in the feeding mechanism, and "bad behaviour" of the lamp becomes pronounced.

Method B is free from this disadvantage, since the lamp is always suspended in its normal position, but in using the mirror a connection has to be made for that portion of the light absorbed by it in reflecting. With a good glass mirror this may be assumed to be about 10 per cent.

The chief difficulty met with in testing an arc light is that of colour and great intensity. The colour of the light is usually very white, and for this reason, as pointed out in Experiment M8, the colour of the standard light should be as nearly as possible white. This can be very nearly attained by using a sub-standard in the form of an "overrun" glow lamp, *i.e.* a 16 C.P. or 32 C.P. glow lamp supplied with about 5 per cent. over its normal voltage. From a previous calibration of this about this voltage against a standard (Experiment M8), its C.P. is known at this higher voltage, and this latter can be maintained constant throughout the experiment by means of a resistance in its circuit. Finally, with regard to the intensity of the light, the lamp has to be placed a considerable distance from the photometer screen. This distance is reduced somewhat by bending the ray as in method B, and can be reduced to any extent in both methods by revolving a perforated screen in the path of the light to the photometer screen. As, however, this is a complication, it is not recommended in this elementary experiment. Difficulties of both light and intensity can be greatly reduced by the experimenter obtaining balances on the screen by looking at it alternately through "signal-red" and "green" coloured glass plates.

The particular method described here is method B, although the procedure is general for both methods A and B.

Diagram of Connections.—

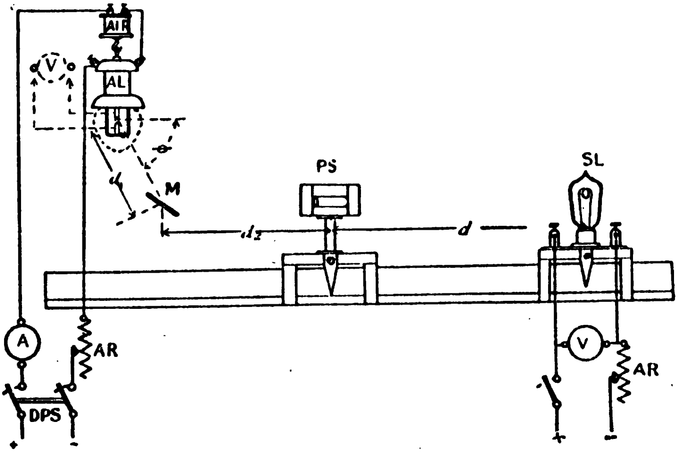

FIG. 65.

Apparatus required.—

AL = arc lamp to be tested.
ALR = arc lamp resistance.
V = voltmeter.
A = ammeter.
AR = adjustable resistance.
DPS = double-pole switch.
+ − = source of steady E.M.F.
M = reflecting mirror.
PS = photometer screen.
SL = standard lamp.

The candle-power of the lamp will be measured in a vertical plane, angles being measured from a horizontal plane through the arc, so that a vertical line is 90° from zero, *i.e.* $\theta = 90°$. The carbons in AL should be carefully adjusted, and the lamp run at normal voltage for a short time previous to making the test.

Method.—(1) Connect up as shown, and adjust the voltage on SL to the required amount by means of AR. It is best to do this only whilst readings are being taken, as if this increased voltage is left on the lamp, blackening of the bulb will take place, and its C.P. will be decreased.

(2) Lower the lamp until the arc is on a horizontal line with PS

and SL. With DPS closed, adjust AR for normal voltage V_m on SL and its resistance ALR; this is to be kept constant whilst measurements are being taken. Adjust the distances d and d_1 until a balance is obtained on PS, judging the intensities of light by the method described above. Quickly check V_m, and measure C on A, and V_a, the volts across the two carbons. Note the distances d and d_1 (d_1 only on lamp side because no mirror is used for horizontal C.P.). Repeat this measurement four times; temporarily reduce volts on SL.

(3) Lift the lamp a short distance and adjust M so that rays from an angle of about 20° are reflected by it along the axis through PS and SL. Make all adjustments (V_m and SL), and obtain a balance by adjusting the position of PS, or SL, or both. Make simultaneous measurements of V_a and C, V_m remaining constant. Note the distances d, d_1, and d_2, and measure the angle θ. Make this measurement four times.

(4) Repeat (3) for values of θ up to 90°, observing the precaution of reducing the voltage on SL between measurements, and of taking values of V_a and C simultaneous with the condition of balance.

Let CP = C.P. of arc lamp,
SL = C.P. of standard lamp,
K_1, K_2 = coefficient of reflection of the one or more mirrors employed (= about 0·9),

$$\text{Then the actual CP} = \text{CP measured} \times \frac{1}{K_1 \times K_2}$$

so that the C.P. at $\theta°$ from the horizontal will be—

$$= \text{SL} \cdot \frac{(d_1 + \text{etc.})^2}{d^2} \cdot \frac{1}{K_1 \times K_2}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
V_m	V_a	C	$\theta°$	d	$(d_1 + \text{etc.})$	$K_1 \times K_2$	C.P. of AL at $\theta°$	Remarks.
								C.P. of SL = —— Particulars of arc lamp ——

During the test V_a and C will vary continuously, but they should be of approximately the same value for all the measurements made.

From the tabulated results above find the average total watts taken by the lamp and its resistance = V_m × aver. C; also the average watts taken by the arc only = aver. V_a × aver. C. Plot the distribution of C.P. in the form of a polar diagram as follows:—

Construct a number of concentric circles whose radii represent C.P. to scale, 100, 200, etc. From their common centre draw faint radial lines at all the angles θ in the table of results above. Step off along these lines the corresponding values of C.P., and finally draw a curve through all these points. The curve so obtained is called the polar diagram of candle-power for the arc lamp.

Results—

RECORD OF EXPERIMENT No. M9.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
V_m	V_a	C	$\theta°$	d	$(d_1 + \text{etc.})$	$K_1 \times K_2$	C.P. of AL at $\theta°$	Remarks.
110	80	5·56	15° above	115	281	0·8	120	C.P. of SL = 16. Particulars of arc lamp Jandus enclosed opal globes, both inner and outer. $K_1 \times K_2$ assumed = 0·8 for two mirrors.
110	81	5·6	horizontal	100	294	0·8	160	
110	80·6	5·6	15	85	306	0·8	260	
110	78·7	5·5	30	66	382	0·8	505	
110	80·3	5·7	44	70	378	0·8	583	
110	81·2	5·7	59	78	408	0·8	350	
110	80·8	5·58	74	90	109	0·8	290	

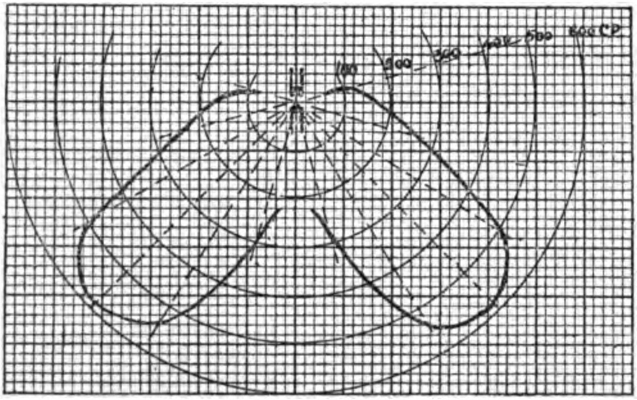

FIG. 66.

Experiment No. M10.—The Distribution of Magnetic Field about a Straight Conductor carrying a Current.

Introduction.—The object of this experiment is to investigate how the magnetic field around a wire carrying a current decreases as distance from the wire increases. The particular method employed to compare the field strengths at the various distances is by observation of the time of oscillation of a freely suspended magnet needle of short length (say 1 cm.).

For such a magnet—

If T = time of a complete oscillation in seconds,
H = strength of field in C.G.S.-lines per sq. cm.,
K = moment of inertia of the needle,
M = magnetic moment „ „

$$T = 2\pi\sqrt{\frac{K}{MH}}$$

$$\text{from which } T^2 = \frac{C}{H}$$

$$\text{and } H = \frac{C}{T^2}$$

where c is a constant for the particular magnet used.

In reality the needle oscillates in the resultant of two fields—

(1) That of the earth H,
(2) „ „ conductor H_1.

The simplest method is to allow the magnet to oscillate in the space where these two fields are parallel to each other, in which case the resultant or actual field around the needle is $H_1 + H$, or $H_1 - H$, according as field of the conductor is in the same or in the opposite direction at that point to that of the earth. This can be easily understood by reference to the two diagrams (*a*) and (*b*), in which the position of the magnet is shown for the two cases above mentioned.

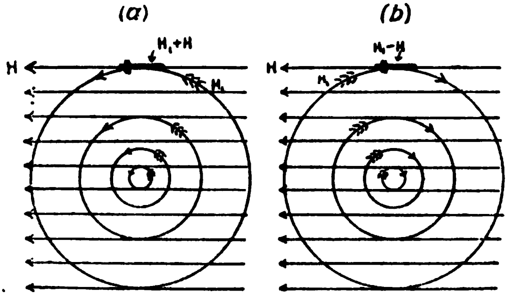

FIG. 67.

If the magnet oscillates in the field $H_1 + H$, its oscillations will be more frequent, and its time of oscillation shorter than would be the case if oscillation took place in the field $H_1 - H$. This is evident from the formula stated above, that—

$$T^2 = \frac{C}{H}$$

$$\text{from which } T \infty \sqrt{\frac{1}{H}}$$

where H in this case is the resultant field.

In the practice of the experiment the time of oscillation is obtained by counting over a short interval of time measured on a stop-clock, and it is found practically impossible in this simple method to count more than 5 or 6 per second, *i.e.* to take T to less than 0·2 of a second. Of the two methods (*a*) and (*b*) given above, that giving the greatest value of T for a given H_1—method (*b*)—is the one recommended here.

Diagram of Connections.—

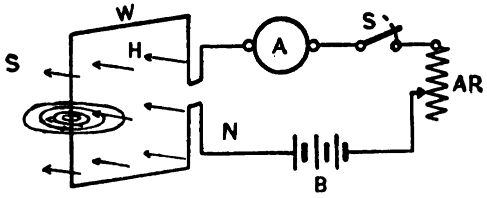

FIG. 68.

Apparatus required.—

W = a number of turns, say 10, of wire on a wooden frame about 1 metre square. A number of wires are used so that a smaller current will suffice to produce a given field; and the frame must be made large so that the fields of the other sides of the square do not appreciably affect the needle.

n = small magnetic needle about 1 cm. long freely suspended about the middle of one side of the square frame.

NS = magnetic meridian.

A = ammeter.

AR = adjustable resistance.

B = source of constant current.

S = switch.

A stop-clock.

Method.—(1) Suspend *n* near the frame, and when it comes to rest in the magnetic meridian, mark its north pole. Draw a line along the meridian (*i.e.* parallel to the length of *n*) on a sheet of paper immediately underneath *n*. Set the *plane* of W at about 90° to the axis of, and intersecting the centre of, *n*.

(2) With S open, give a *very slight* oscillation to *n*. By means of the stop-clock count the time of 10 complete oscillations; divide by 10 to get T in the earth's field H.

(3) With the centre of *n* about 5 cms. from the conductors on W, close S and adjust the direction of the current C so that, on switching on, *n* turns through 180° with its North pole pointing due South. This position is so when the length of *n* is parallel to the line previously drawn on the paper underneath. In this adjustment it may be necessary to move the needle slightly out of the plane of the coil, but this is of no consequence so long as the adjustment so made is not greater than, say, 20° or 30°. Adjust C to about 2 or 3 ampères for the above dimensions of apparatus, and keep this constant throughout the experiment.

(4) With S still closed, find the time of complete oscillation, T_1, of *n*. Measure the distance *d* from the centre of the needle to the conductors on W.

(5) With the same value of C, repeat (3) and (4) for increasing values of *d* up to about 20 cms., taking readings more frequently for small values of *d* and less frequently as *d* increases. Note the corresponding values of T_1 and *d*.

$$\text{Then, since } H = \frac{C}{T^2}$$

$$H_1 - H = \frac{C}{T_1^2}$$

$$\text{so that } H_1 - H + H = \frac{C}{T_1^2} + \frac{C}{T^2}$$

$$\text{from which } H_1 = C\left(\frac{1}{T_1^2} + \frac{1}{T^2}\right) \text{ or } H_1 \propto \left(\frac{1}{T_1^2} + \frac{1}{T^2}\right)$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Current. Ca.	Distance, d cms.	Time of complete oscillation		$\frac{1}{T^2}$	$\frac{1}{T_1^2}$	$\frac{1}{T_1^2}+\frac{1}{T^2}$ representing field due to C.	Remarks.
		in earth's field, H, T secs.	in resultant field, $H_1 - H$, T_1 secs.				

Plot a curve showing the relation between $\frac{1}{T_1^2}+\frac{1}{T^2}$ and d, taking values of d as abscissæ.

This curve shows how the field due to C falls off with distance from the conductor. By inspection this curve shows that H_1 falls off as d increases, but the exact relation between them is not easily seen. Try plotting a curve between values of $\frac{1}{T_1^2}+\frac{1}{T^2}$ and $\frac{1}{d}$. If this curve is a straight line, then $H_1 \propto \frac{1}{d}$.

State the conclusions you draw from the results obtained.

Results.—

RECORD OF EXPERIMENT No. M10.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Current, Ca.	Distance, d cms.	Time of complete oscillation		$\frac{1}{T^2}$	$\frac{1}{T_1^2}$	$\frac{1}{T_1^2}+\frac{1}{T_2}$ representing field due to C.	Remarks.
		in earth's field, H, T secs.	in resultant field, $H_1 - H$, T_1 secs.				
2·7	5	1·9	1·1	0·277	0·826	1·103	
„	6	„	1·2	„	0·694	0·971	
„	7	„	1·4	„	0·510	0·787	
„	9	„	1·64	„	0·334	0·611	
„	12	„	1·9	„	0·277	0·554	

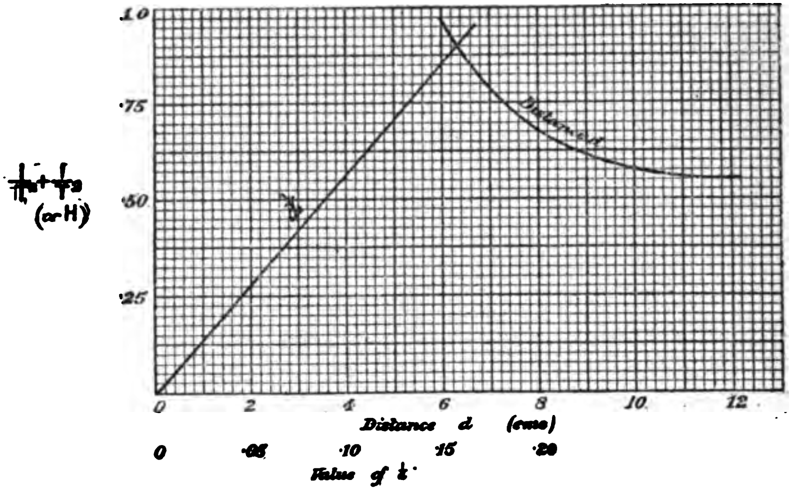

Fig. 69.

Experiment No. M11.—Attractive Force of an Electro-Magnet.

Introduction.—To find the relation within the limits of the experiment between the attractive force and the current passing through the coils of an electro-magnet.

Diagram of Connections.—

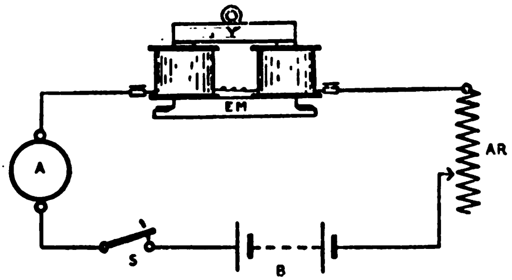

Fig. 70.

Apparatus required.—

EM = electro-magnet.
Y = yoke of soft iron.
B = battery or other source of steady current.
A = ammeter.
S = switch.
AR = adjustable resistance.
SB = spring balance.

Method.—(1) Take reading of SB with yoke Y hooked on: call this p lbs.

(2) Choose a good position for Y on pole-faces of EM, so that it lies quite flat, and mark this off on EM. For all subsequent readings Y must be placed in exactly the same position. With S open and Y in position, hook the spring-balance to the ring of Y, hold SB vertical and lift gently, noting the exact reading on its scale when the magnet suddenly releases its yoke. Do this two or three times, and call the reading on SB, P lbs.

(3) Insert maximum resistance in AR, place Y in position, and close S. Carefully note C and the new pull on the spring-balance required to release the yoke.

(4) Slightly increase C by adjusting AR, break circuit, place yoke in position, and then close S and repeat (3).

(5) Repeat for gradually increasing values of C, carefully noting in each case the current and the reading on SB.

(6) Repeat for gradually decreasing values of C, momentarily breaking circuit between readings.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Initial reading on SB, p (lbs.).	**Readings on SB, P (lbs.).**	**Attractive force, $P - p$ (lbs.).**	**Current in amps., C.**	**Remarks.**
				} **Ascending.**
				} **Descending.**

Plot curves showing the relation between C and $P - p$ for both ascending and descending values of C, taking values of C as abscissæ, and of $P - p$ as ordinates.

Draw an average curve midway between the two curves, and state what you conclude from its appearance.

Results.—

RECORD OF EXPERIMENT NO. M11.

I.	II.	III.	IV.	V.
Initial reading on SB, p (lbs.).	Readings on SB, P (lbs.).	Attractive force, $P - p$ (lbs.).	Current in amps., C.	Remarks.
1	2·5	1·5	0	Residual.
”	13	12	0·05	
”	15	14	0·1	
”	51	50	0·2	
”	83	82	0·25	
”	76	75	0·3	Ascending.
”	108	107	0·35	
”	118	117	0·4	
”	135	134	0·5	All readings are aver-
”	141	140	0·55	ages of three for
”	136	135	0·55	each current.
”	128	127	0·45	
”	109	108	0·35	Descending.
”	83	82	0·25	
”	45·5	44·5	0·15	
”	11·5	11·4	0·1	
”	3	2	0	Residual.

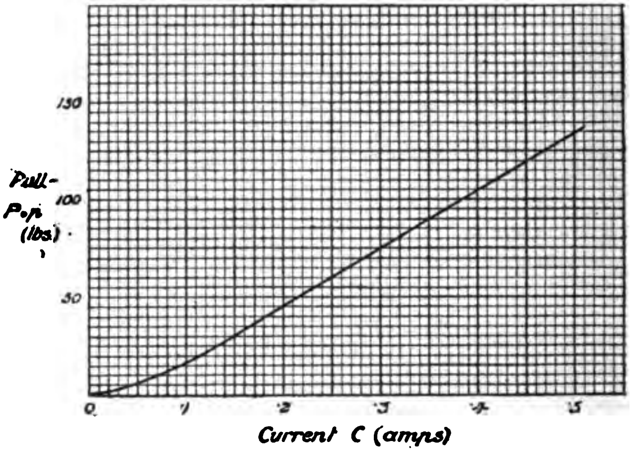

FIG. 71.

Experiment No. M12.—Influence of Air-gap on Attractive Force of an Electro-Magnet.

Introduction.—To find relation between attractive force of an electro-magnet and width of air-gap between pole-face and yoke for a given magnetizing current.

Diagram of Connections.—

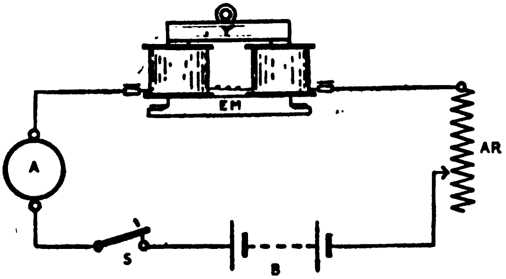

Fig. 72.

Apparatus required.—

EM = electro-magnet.
Y = yoke of soft iron.
B = battery or other source of steady current.
A = ammeter.
S = switch.
AR = adjustable resistance.
SB = spring-balance.
A number of strips of non-magnetic material (say brass) of various thicknesses.
A micrometer.

Method.—(1) Take reading of spring-balance with Y hooked on: call this p lbs.

(2) Choose a good position for Y on pole-face of EM, so that it lies quite flat. Attach the spring-balance hook to the ring of the yoke, and lift vertically until the yoke is suddenly released. Note accurately the reading on the spring-balance, say p_1 lbs.

(3) Adjust AR to give a convenient current, C amps, and with yoke in position, close S. C is to be kept at exactly this value throughout the experiment. Find P (lbs.) now required to release the yoke. Then for no air-gap the attractive force due to current C is equal to $P - p_1$.

(4) With C unaltered and S still closed, place the thinnest strip of brass flat on the pole-faces, then the yoke carefully on top. Find P (lbs.) to detach the yoke; then the actual attraction due to the

current C is found by subtracting p from this and all subsequent readings. Note $(P - p)$ lbs. and the thickness of the brass strip (air-gap).

(5) Repeat (4), with S unopened, for various increasing widths of air-gap, noting $(P - p)$ in each case, and t the width of air-gap.

(6) Repeat (5) for decreasing air-gaps.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.
Weight of yoke, p (lbs.).	Initial pull, p_1 (lbs.).	Pull, P (lbs.).	Attractive force, $P-p$ (lbs.).	Current, C (amps.).	Width of air-gap (mms.).	Remarks.

Draw a curve showing the relation between attractive force $P - p$ and width of air-gap t, plotting t as abscissæ and $P - p$ as ordinates.

State what you conclude from the experiment.

Results.—

RECORD OF EXPERIMENT No. M12.

I.	II.	III.	IV.	V.	VI.	VII.
Weight of yoke, p (lbs.).	Initial pull, p_1 (lbs.).	Pull, P (lbs.).	Attractive force, $P-p$ (lbs.).	Current, C (amps.).	Width of air-gap (mms.).	Remarks.
1·25	1·75	1·75	—	—	—	All readings are averages of three for each current.
"	"	86	82	0·5	0·35	
"	"	38	36	0·5	0·62	
"	"	31	29	0·5	0·85	
"	"	13	11·25	0·5	1·35	
"	"	10	8·25	0·5	1·65	
"	"	6·25	5	0·5	2·48	
"	"	4	2·25	0·5	3·4	
"	"	1·6		0·5	6·44	

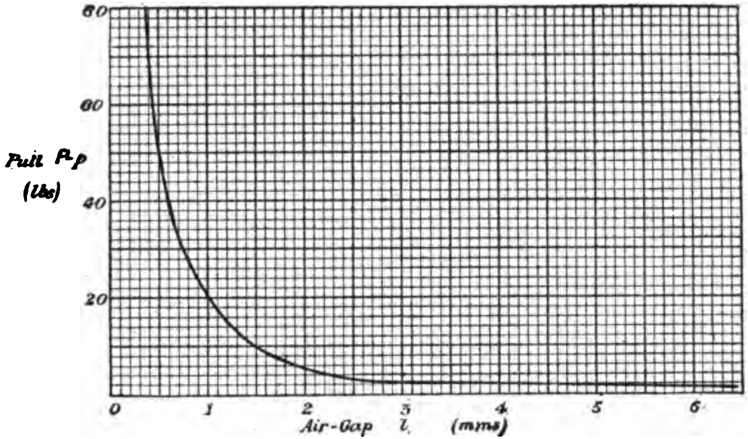

FIG. 73.

Experiment No. M13.—Experiments on an Electro-magnet.

Introduction.—The attractive power of an electro-magnet depends on two factors: (*a*) the induction of lines B; (*b*) the area of contact between its pole-faces and the armature A.

If B = the number of C.G.S. lines passing through every square centimetre of contact surface between poles and armature,

and A = the area of contact in square centimetres,

$$\text{Then } P = \frac{B^2A}{8\pi},$$

where P = pull on armature in dynes.

So that P in grams will be—

$$P = \frac{B^2 . A}{981 \times 8\pi}.$$

This experiment is to show that $P \propto B^2$, and the method adopted is to take advantage of the fact that B can be measured by the throws of a ballistic galvanometer[*] needle attached to a coil enclosing the lines of force passing from the magnet to the armature.

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[*] The theory of the ballistic galvanometer is not given here; it will be found in any good text-book: it is sufficient at this stage for the student to assume the law stated above. Neither the theory nor the dimensions of the particular galvanometer employed is necessary in conducting the experiment.

Diagram of Connections.—

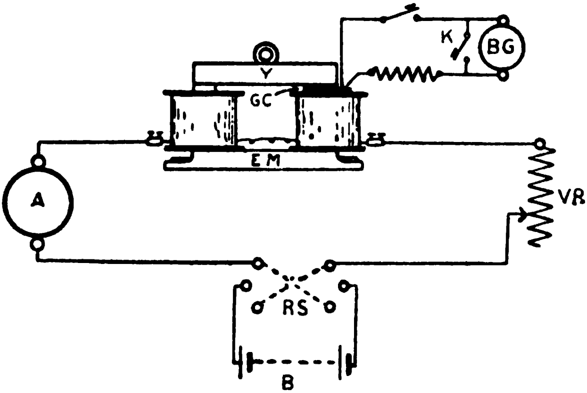

FIG. 74.

Apparatus required.—
EM = electro-magnet.
A = ammeter.
VR = variable resistance.
Y = yoke or armature.
RS = reversing switch.
B = source of constant-current supply.
BG = ballistic galvanometer.
R = resistance.
GC = galvanometer coil.
K = damping key.
Spring-balance or other apparatus to measure pull on armature.

Method.—(1) Connect up as above, taking care to insert R (about 1000 ohms) in series with BG. In placing the armature each time, observe the precautions enumerated in (2) Experiment M11.

(2) Make a preliminary test to find the best value of R, so that the throw is on the scale with C of the maximum value likely to be attained in the experiment: this R must be kept constant throughout.

(3) Insert maximum resistance in VR, break BG circuit, and, after closing main switch, reverse a few times by RS, finally leaving in say left-hand position with current switched on. Attach the spring-balance to the yoke, and find the pull necessary to release Y, observing the precaution of steady vertical lifting. Note P.

(4) Break main circuit (not reverse), and replace Y in as nearly as possible the same position it had formerly; then close the circuit. It is of great importance that the position of Y and the current indicated on A should be the same as before.

(5) Close the BG circuit, and read the "zero" position of the spot. Carefully watch this spot, and suddenly reverse the main current by RS. The spot suddenly moves over the scale, and then oscillates about its original position. Its maximum movement from zero position is called the throw, and this must be carefully noted. The spot is brought to rest by short-circuiting BG by means of K.

(6) Open K and break BG circuit. Then decrease VR, thereby increasing C, and repeat operations (3), (4), and (5), taking particular care to reverse the main current about ten times before finally leaving it switched on in the same direction as in (2).

(7) Repeat for various values of C, noting values of P and throw in each case.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
C (for reference only).	Pull, P.	Throw on B.G.	Remarks.

Plot a curve showing the relation between P and throws on BG, which latter represent the inductions B, taking values of P as ordinates, and of throw for abscissæ.

The curve follows the general law—

$$P = K . B^n,$$

where K and n are constants.

Find the value of n, which, according to the formula, should be 2.

Experiment No. M14.—Experiments on an Electro-Magnet.

Introduction.—In the previous experiment it is stated that the pull of an electro-magnet on its yoke is proportional to the square of the induction multiplied by the area of contact, or that $P \propto B^2 . A$. The object of this experiment is to prove that $P \propto A$.

This is accomplished by using magnet-cores of the same material but of various areas of cross-section, and finding the pull on a soft-iron yoke when the coils are supplied with the same magnetizing force or ampere-turns per centimetre, in which case it may be taken that B is approximately the same in all yokes. If each pair of coils is wound with the same number of turns, the magnetizing force, and therefore B, will be the same in each magnet-core for the same current.

Diagram of Connections.—

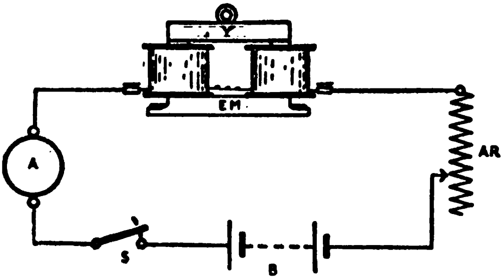

Fig. 75.

Apparatus required.—

EM = electro-magnet.
Y = yoke of soft iron.
B = battery or other source of steady current.
A = ammeter.
S = switch.
AR = adjustable resistance.
SB = spring-balance.

Also similarly shaped electro-magnets, but of various areas of cross-section, with corresponding yokes; all of the same material. *Note:* In each magnet the cross-section is the same as the pole-face.

Method.—(1) Connect up the smallest magnet as above, and, after measuring its pole-face area a_1, place its yoke (of the same sectional area a_1) in its exact central position. With C = 0, find the initial force p_1 to lift the yoke off the magnet.

(2) Close the main circuit and find P_1 for increasing values of C (Experiment No. M11), carefully observing all the precautions there enumerated. Then the actual attraction is $P_1 - p_1$.

(3) Repeat (2) for the next larger sized magnet, finding the relation between C and $P_2 - p_2$, when p_2 is the new initial pull for the larger core of the same area of cross-section as the magnet, a_2.

(4) Repeat (3) for larger sizes.

In each case yokes of the same area of cross-section as the magnet-core should be used, and the initial pulls, p_1, p_2, etc., found on open circuit.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Area, A.	Initial pull, p.	Total pull, P.	Attraction, $P-p$.	Current (or amp.-turns), C.	Remarks.

On the same diagram plot curves for each area, showing the relation between C and $P-p$.

Erect ordinates at about six values of C to cut all curves: the intersections give values of $P-p$ for each area for the same C or induction B. From the values so obtained make a table as follows:—

I.	II.	III.	IV.
Current (or amp.-turns), C.	Area, A.	Attraction, $P-p$.	Remarks.

From these values plot curves for each of the values of C, showing the relation between A and attraction $P-p$.

If these are straight lines, then $P \propto A$.

Experiment No. M15.—Measurement of Magnetic Permeability—Thompson's Permeameter.

Introduction.—In a previous experiment it has been stated that the attractive force between two surfaces having an induction B lines per sq. cm. is—

$$P = \frac{B^2 A}{8\pi}$$

where P = attraction in dynes,
A = area of contact in sq. cms.

That this is so has been verified by Experiments M13 ($P \propto B^2$) and M14 ($P \propto A$). If the attractive power of a number of substances of the same size and under the same conditions of magnetizing force be compared with each other, results will be obtained which will represent in some measure their relative magnetic quality or permeability. Professor S. P. Thompson has devised an instrument, called the permeameter, for such work. The results obtained are, of course, only approximate, but the comparison can be made quickly and with sufficient accuracy to justify the use of the method for workshop measurements. From the above formula—

$$P \text{ in grams} = \frac{B^2 . A}{8\pi \times 981},$$

$$\text{from which } B = \sqrt{\frac{8\pi \times 981 \times P}{A}}.$$

If P be measured in lbs., and A in sq. inches then clearly—

$$B \text{ per sq. cm.} = \sqrt{\frac{8\pi \times 981 \times 453P}{A \times 2{\cdot}54^2}},$$

$$\text{from which } B = 1317\sqrt{\frac{P}{A}}$$

where B = lines per sq. cm.,
P = pull in lbs.,
A = area of contact in sq. inches.

The instrument is a special form of electro-magnet, designed so that the exact conditions of surface contact, etc., can be repeated with a number of specimens, thus ensuring that the results will be comparative with the same magnetizing current.

Diagram of Connections.—

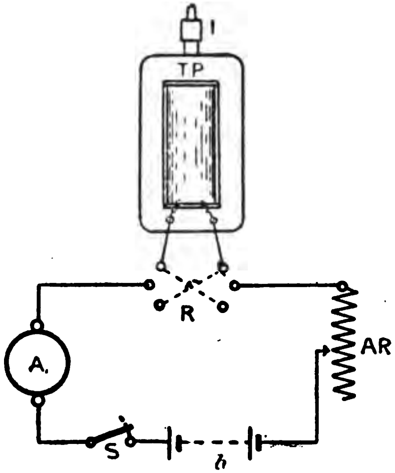

FIG. 76.

Apparatus required.—

TP = permeameter.
I = iron specimen.
b = source of steady current.
A = ammeter.
AR = adjustable resistance.
RS, S = reversing switch and switch.
Specimen bars of different irons.

Method.—(1) Place the first specimen bar I carefully in position. Close S, and diminish the magnetizing current C as indicated on A, gradually to zero value. Whilst this is being done, reverse the direction of C continuously by rocking RS, taking care to make a large number of rapid reversals as C approaches zero. These operations should eliminate all traces of residual magnetism in the bar I. Adjust AR so that A indicates a small current (say 0·01 to 0·1 amp.). With S still closed, reverse a number of times by RS, finally leaving it in a direction which must be the same for each measurement.

(2) Attach SB to the hook of the specimen I, and, observing all the precautions enumerated in Experiments M11 and M12, find the mean value of a number of pulls required to overcome the attraction between the specimen and IP. Note the values of C and P.

(3) Increase C slightly by adjustment of AR, and repeat (2), taking care to have C in the same direction as (2) after a number of reversals. Note the mean value of P from a number of tests, and the corresponding value of C.

(4) Repeat for increasing values of C until no further, or only a very slight, increase of P takes place. Note P and C in each case, taking large increments of C towards the end of the test. Make in all about twenty tests.

(5) Repeat for the other specimen bars.

Comparison of Induction B and Permeability μ.

Let L = length of magnetizing coil on TP,
S = number of turns of wire on the coil,
C = current through the coil (amps.),

$$\text{Then } H = \frac{4\pi}{10} \cdot \frac{C \cdot S}{L}$$

where H = magnetizing force producing the induction B.

For the particular permeameter employed, the term $\frac{4\pi}{10} \cdot \frac{S}{L}$ is a constant quantity.

$$\text{So that } H = K \cdot C,$$

where $K = \frac{4\pi}{10} \cdot \frac{S}{L}$, and is found from the permeameter coil.

The area of the bar is found by direct measurement, and the value of the permeability μ is found from—

$$\mu = \frac{B}{H}$$

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Area of contact, A sq. ins.	Constant, K.	Force, H = KA.	Current, C amps.	Mean pull, P lbs.	Induction, B per sq. cm.	Permeability, $\mu = \frac{B}{H}$	Remarks.
							Particulars of specimen.

In the table, A is given in sq. inches, and P in lbs., because the spring-balance is usually graduated to read lbs.; so that B is found from the formula—

$$B = 1317\sqrt{\frac{P}{A}}\ ^{*}$$

Plot a curve for each specimen, showing the relation between H and B.

Also plot a curve for each specimen, showing the relation between B and μ.

Experiment No. M16.—Hysteresis Tests—Ewing's Tester.

Introduction.—This method forms a quick and convenient method of comparing the hysteresis of a sample of iron with that of a standard specimen. When a piece of iron is subjected to a rapidly varying flux, corresponding changes of magnetization take place in the iron specimen, and these changes of magnetization "lag behind" the magnetizing force, due to the tendency of the iron to persist in the magnetic state previously acquired. This tendency of "lagging behind" is called "magnetic hysteresis," and the greater the tendency to lag behind, the greater the hysteresis of the specimen. If, then, a piece of iron be rotated between the poles of a magnet, an unbalanced force will be set up between the two, and the greater the hysteresis of the sample the greater will be the unbalanced force. This principle has been applied by Professor Ewing, in his instrument for comparing the hysteresis of samples of iron. The samples are made of five or six stamped pieces 3 inches long, $\frac{5}{8}$ inch wide, and about 1 mm. thick. These are rotated between the poles of a swinging permanent magnet, which is deflected from the vertical, causing a pointer to move over a scale, the deflections on which represent the hysteresis of the specimen.

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[*] This is a sufficiently accurate formula. Really, $B = 1317\sqrt{\frac{P}{A}} + H$, because the coil remaining fixed, the pull is that due to $B - H$ lines.

Diagram of Connections.—

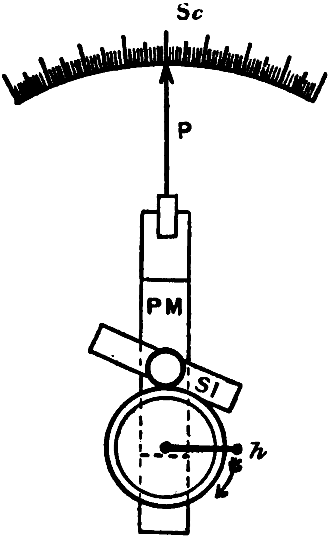

Fig. 77.

Apparatus required.—

PM = permanent magnet
p = pointer
Sc = scale
h = handle to rotate SI
} = hysteresis tester.
SI = specimen of iron.

Method.—(1) Set the instrument facing towards magnetic north and south. Let the knife-edge of the magnet down on its agate bearing, and adjust the balance nuts so that the pointer swings to a zero position about the middle of the scale. Then raise the magnet off its bearings. Turn the carrier into a horizontal position, and fix one of the standard bundles of strips by means of the clamps and ebonite plate, taking care to push all the strips up against the stop at one end, so that all the ends are flush.

(2) Turn the handle slowly, and, while the specimen is turning, let the magnet gently down on its bearings. Note the scale-reading on one side, while the handle is being rotated just fast enough to give a steady reading. Then reverse the rotation, and take the reading on the other side. Then either the average or the sum of these two readings represents the hysteresis of the specimen.

(3) Repeat for the other standard specimen provided.

(4) Repeat for the specimen to be tested.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Specimen No. and Description.	Deflections.			Remarks.
	Right.	Left.	Sum.	

To compare the hysteresis of the specimen tested, plot the value of the known hysteresis and deflection of each of the two standard specimens provided. The hysteresis of each is given for a B of 4000, and the curve can be plotted directly.

Join the two points so obtained by a straight line. Then, since the hysteresis of the specimen is proportional to its deflection (the instrument is calibrated so), the hysteresis of the specimen tested is found by referring to its deflection on the curve.

State the hysteresis of the specimen in—
ergs. per c.cm. per double reversal, and
watts per lb. at 100 ∼
Both these are given for the standard specimens for B = 4000 per sq. cm.

To find the relative hysteresis for any other induction, the following table of factors can be used—

Induction B per sq. cm.	Relative amounts of hysteresis.
2000	0·33
2500	0·47
3000	0·63
4000	1·00
5000	1·41
6000	1·89
7000	2·41
8000	3·00

State how the above table is obtained.

Results.—

RECORD OF EXPERIMENT No. M16.

Standard specimens, five pieces each 3″ × $\frac{5}{8}$″ stampings.
Standards for B = 4000 per sq. cm.
No. 1056. Hysteresis loss: ergs per c.cm. per dbl. reversal = 770
„ „ watts per lb. at 100 ~ . = 0·45
No. 2056 „ ergs per c.cm. per dbl. reversal = 1600
„ „ watts per lb. at 100 ~ . = 0·95

Results.—

I.	II.	III.	IV.	V.
Specimen No. and Description.	Deflections.			Remarks.
	Right.	Left.	Sum.	
Standard No. 2056	62	58	120	
Standard No. 1056	36	33	69	
Test-pieces	46	43	89	

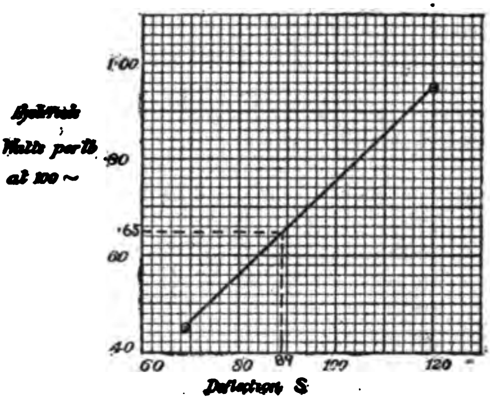

FIG. 78.

From the above curve it is seen that the test-piece with deflection 89 has hysteresis loss = 0·65 watts per lb. per 100 ~ .

Experiment No. M17.—Experiment on an Electric Bell.

Introduction.—The experiment is to find—

(*a*) The least current required to ring an electric bell when the hammer and contact screw are adjusted to what may be termed "normal working position."

(*b*) The effect of position of armature on the current passing through the bell and the volts at its terminals (as measured by an ammeter and voltmeter in the circuit). An electric bell is essentially an apparatus using intermittent current, the circuit being automatically made and broken by the bell itself. Thus the readings on the ammeter and voltmeter are "time averages" of currents and volts respectively.

(*c*) The effect of position of armature on the "apparent" ohmmic resistance of and watts taken by the bell, as calculated from (*b*).

Diagram of Connections.—

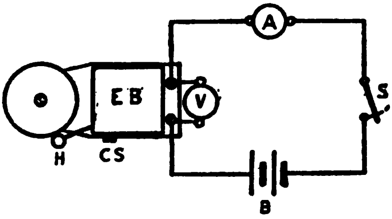

Fig. 79.

Apparatus required.—

EB = electric bell.
B = battery of two Leclanché cells.
A = low reading ammeter, dead beat.
V = low reading voltmeter, dead beat.
S = switch.
CS = contact screw of bell.
H = hammer and armature of bell.

Method.—(1) Make connections as in diagram, close circuit momentarily to see that A and V are reading on their scales.

(2) Close S, and adjust CS so that the hammer strikes the gong with what is, in the opinion of the experimenter, the frequency giving the best tone, etc., for the particular bell employed. This will, of course, be a matter of judgment only.

(3) Insert an adjustable resistance of about 50 ohms in the main

circuit, and decrease the current until the hammer only *just* oscillates. Note this current.

(4) Repeat (3) by inserting all the resistance and then increasing the current until the hammer again only *just* oscillates. Note this current.

The mean of these two values of C is the minimum current to ring the bell with the armature in its normal position, and might be termed the "figure of merit" of the bell.

(5) Disconnect the adjustable resistance and connect up the circuit as in the diagram. Advance the screw CS towards H so that the frequency of the strike increases; advance it to such a position that the hammer *just* ceases to strike. Do this two or three times so as to get the proper position, and when this has been obtained, and with S still closed, measure C and V.

(6) Repeat (5) by screwing CS too far and then away from H, and so get C and V again. The average C and V of (5) and (6) are the values of current and volts required.

(7) Adjust CS accurately to the position found in (5) and (6). Rotate it away from H by exactly half a revolution (as shown by the slot in the screw head or by a wire through it). With S still closed, take readings of C and volts E.

(8) Rotate another half-revolution and again note C and E.

(9) Repeat (8) until oscillation ceases.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Turns from inside stop position.	Current, C (amps.).	Volts, E.	Apparent resistance, R (ohms).	**Watts.**	**Remarks.**
					"Figure of merit" = —— amp.

On the same diagram plot curves showing the relation between turns and C, E, R, and watts. Also draw a curve showing the relation between C and E. State generally what conclusions you draw from the curves.

Results—

RECORD OF EXPERIMENT NO. M17.

I.	II.	III.	IV.	V.	VI.
Turns from inside stop position.	**Current, C (amps.).**	**Volts, E.**	**Apparent resistance, R (ohms).**	**Watts.**	**Remarks.**
0	0·2	1·58	7·9	0·316	"Figure of merit" = 0·05 amps.
5	0·16	1·72	10·8	0·275	
1	0·144	1·93	13·4	0·273	
1·5	0·133	1·9	14·3	0·253	
2	0·105	2	19	0·21	
2·5	0·103	2·1	20·4	0·216	
3					Out of range.

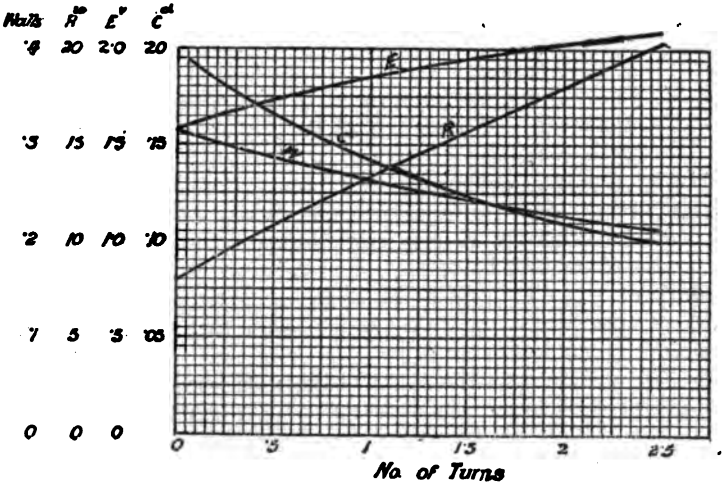

FIG. 80.

Experiment No. M18.—Experiments on Fuses.—Relation between Fusing Current and Diameter.

Introduction.—To find the relation between fusing current and diameter of wires of various metals. The experiment is to be performed with wires connected horizontally, and whose length is large compared with their diameters (all say 15 cms. long), so that the cooling effect of the terminals may be reduced to a minimum. (See Experiments M19 and M20.)

Diagram of Connections.—

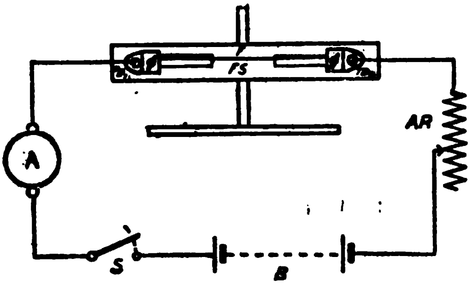

FIG. 81.

Apparatus required.—

F = fuse.
FS = fuse-stand, having hard-wood tilting back with slots for terminals.
TB_1, TB_2 = terminal blocks.
A = ammeter.
AR = adjustable 20 amp. resistance (fine adjustment).
B = source of steady E.M.F.
S = switch.
A micrometer measuring to 0·01 mm.
Sets of at least four undamaged wires of various diameters and in different metals, say, copper (tinned and untinned), aluminium, and lead.

Method.—(1) Fit up as in figure, adjusting the stand so that its face is horizontal, and TB_1 and TB_2 so that the length l is not less than 15 cms.

(2) Commence with the copper wires: choose the largest, measure its diameter accurately, and connect it between the blocks TB_1 and TB_2. Care should be taken in this operation so that the wire is undamaged and lies slack, not tight, between the terminals. Close S, and decrease AR slowly until the wire glows red-hot. Now increase C *very slowly*, one observer watching A and the other AR

and F. Note the fusing current and the behaviour of the fuse when "blown," and the appearance of the broken ends, etc.

(3) Repeat (2) for the remaining diameter of copper wire, noting carefully in each case to increase c very slowly near melting point. Note C and d in each case.

(4) Repeat (2) and (3) for each series, noting all the above points in each case.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Diameter of wire in mms.	Fusing current, C (amps.).	Length and environment of fuse.	Material.	Remarks.
			Copper (untinned)	
			Copper (tinned)	
			Aluminium	
			Tin	
			Lead	

On the same diagram plot curves showing the relation between C and d for each metal, taking values of d as abscissæ and of C for ordinates.

State generally what conclusions you derive from the curves obtained.

Assuming that the law for each curve is of the order—

$$C = m \, . \, d^n + K$$

find the values of m and n for each material.*

---

* See Chap. I., "The Graphical Representation of Experimental Results."

Results—

RECORD OF EXPERIMENT No. M18.

I.	II.	III.	IV.	V.
Diameter of wire in mms.	Fusing current, C (amps.).	Length and environment of fuse.	Material.	Remarks.
21 S.W.G. 0·813	55	Open to air, length = 15 cms.	Untinned copper	All wires cleaned.
0·813	54			
23 S.W.G. 0·61	38			
0·61	37			
25 S.W.G. 0·508	28·5			
0·508	28·5			
28 S.W.G. 0·376	18			
0·376	18·5			
33 S.W.G. 0·254	10·5			
0·254	10·5			
0·813	54	Do.	Tinned copper	All wires cleaned.
0·813	54			
0·61	37			
0·61	37			
0·508	29			
0·508	28			
0·376	18·5			
0·376	18			
0·813	9	Do.	Tin wire	All wires cleaned.
0·813	8·5			
0·56	6			
0·56	5·5			
0·41	4			
0·41	4			
1·6	1·8			
1·6	1·8			

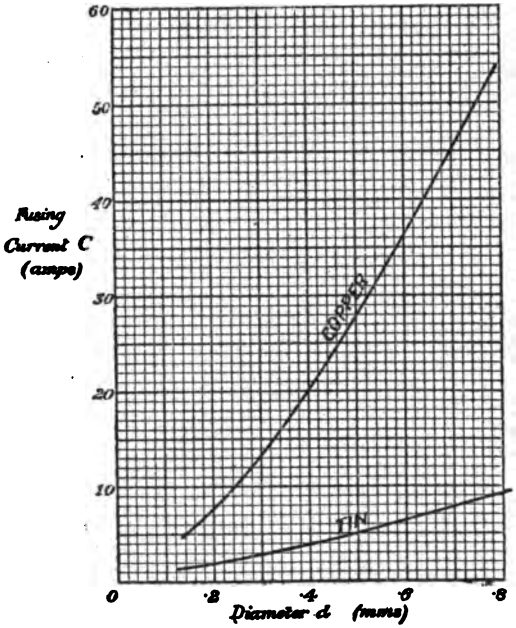

FIG. 82.

Experiment No. M19.—Experiments on Fuses.—Relation between Fusing Current and Diameter of Wires in different Positions.

Introduction.—This experiment is to show the effect of position of a fuse exposed to the atmosphere on its fusing current. The current required to melt a fuse is greater the greater the cooling effect of the atmosphere surrounding it. By far the greater part of the heat developed in a fuse is carried away by the air immediately in contact with it being heated, thus rising due to expansion and making room for colder air to take its place. Thus there is formed a continuous stream of cool air, brushing against the surface of the wire, and rising practically vertically, taking the heat away by convection currents. If the wire is horizontal, this cooling effect is greater than if the same wire were placed vertically upright; since in the former case heat is given up to cool air over the whole length of fuse, whereas in the latter case air warmed by the lower portion of the wire rises vertically all along the wire, and being already warm does not receive as much additional heat as cool air would. Thus, with the same current passing through, the wire will attain a higher temperature when placed vertically, and will therefore require a smaller current to fuse it. For any other position of the wire the fusing current will be between the above two limits.

Diagram of Connections.—

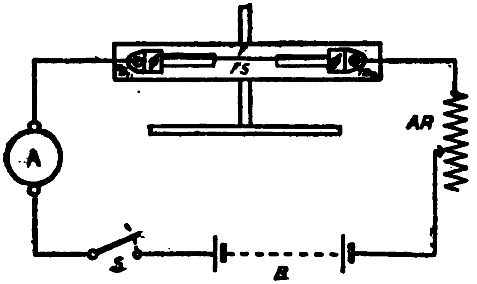

Fig. 83.

Apparatus required.—

F = fuse.
FS = fuse-stand.
TB_1, TB_2 = terminal blocks.
A = ammeter.
AR = adjustable 20 amp. resistance (fine adjustment).
B = source of steady E.M.F.
S = switch.

A micrometer measuring to 0·01 mm.

Undamaged wires of the same metal, and of various diameters.

Method.—(1) Fit up the apparatus as in the figure, placing the fuse horizontally, and using a length of about 15 cms.

(2) Close S and slowly increase the current up to fusing point. Carefully note C for two tests, and measure the diameter of the wire. In all operations carefully observe all the precautions enumerated in the method of experiment M18.

(3) Repeat (2) for the whole range of wires of different diameters, making two observations for each, and noting values of C and *d*.

(4) Repeat (1), (2), and (3) with the wires placed vertical.

(5) Repeat with the wires inclined at an angle of 45°.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.
Diameter of wire in mms.	Fusing current, C (amps.).	Position and environment of fuse.	Material.	Remarks.
		Horizontal		
		Vertical		
		Inclined at 45°		

On the same diagram plot curves showing the relation between C and *d* for each of the positions above, plotting values of C as ordinates, and of *d* as abscissæ.

From the curves find approximately the amount by which the fusing current is increased by changing from the vertical position to 45°, and to horizontal.

Results—

RECORD OF EXPERIMENT NO. M19.

I.	II.	III.	IV.	V.
Diameter of wire in mms.	Fusing current, C (amps.).	Position and environment of fuse.	Material.	Remarks.
0·61 0·508 0·376 0·254	37 28·5 18 10·5	Horizontal	Tinned copper	
0·61 0·508 0·376 0·254	35 27 17 10	Vertical	Do.	
0·61 0·508 0·376 0·254	36 28 17·5 10·5	Inclined at 45°	Do.	

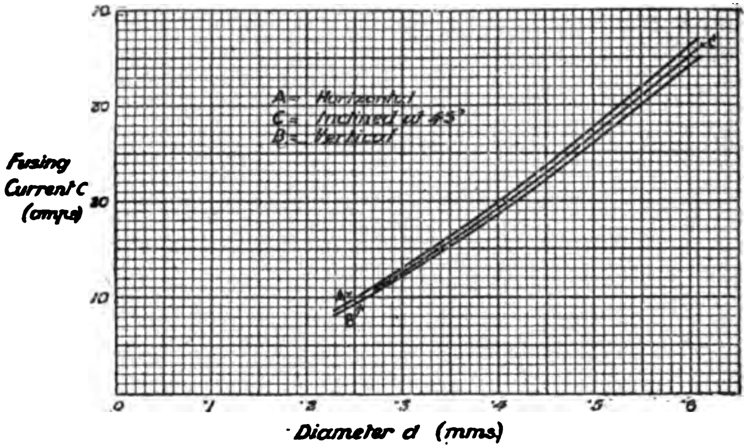

FIG. 84.

Experiment No. M20.—Experiments on Fuses.—Relation between Fusing Current and Length of Fuse.

Introduction.—If a heated metal wire is supported by metal terminals, the wire is cooled somewhat by conduction of heat from it to the metal of the terminals. This cooling effect is greater the larger the terminals and the closer they are together, *i.e.* the shorter the wire. The experiment is to show the effect on the fusing current of having a short wire fastened to large terminals.

Diagram of Connections.—

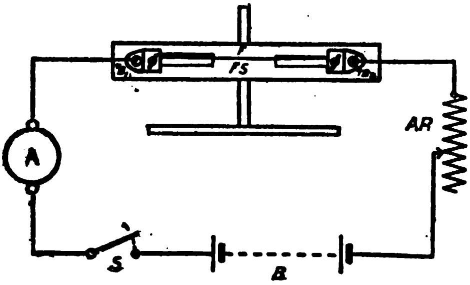

FIG. 85.

Apparatus required.—

F = fuse.
FS = fuse-stand.
TB_1, TB_2 = terminal blocks (each about 4 ozs.).
A = ammeter.
AR = adjustable 20 amp. resistance (fine adjustment).
B = source of steady E.M.F.
S = switch.

A micrometer measuring to ·01 mm.

Undamaged wires of the same metal and of the same diameter.

Method.—(1) Fit up as in figure, the fuse being horizontal, and *l* adjusted to about 15 cm.

(2) Find the fusing current for this fuse with the longest length. Note C and *l*.

(3) Reduce *l* by about 2 cms., and use a new piece of the same wire. Note C and *l*.

(4) Repeat for about six values of *l*, noting in each case the values of C and *l* accurately, and, as far as possible, following the same procedure in each test.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
Length of fuse, *l* (cms.).	Fusing current, C (amps.).	Particulars of fuse wire.	Remarks.
		Horizontal. Diameter = mms. Metal.	Size, etc., of terminals.

Plot a curve showing the relation between fusing current C and length of fuse *l*, plotting values of *l* as abscissæ and of C as ordinates.

State your conclusions drawn from the curves.

Results—

RECORD OF EXPERIMENT NO. M20.

I.	II.	III.	IV.
Length of fuse, l (cms.).	Fusing current, C (amps.).	Particulars of fuse wire.	Remarks.
15	10·5	Tinned copper. Horizontal. Diameter = 0·254 mms.	Terminals, brass, 500 gms. weight each.
15	10·5		
13	10·5		
13	10·6		
10	10·9		
10	10·8		
7	11		
7	11·1		
4	11·8		
4	11·8		
2	16		
2	16		

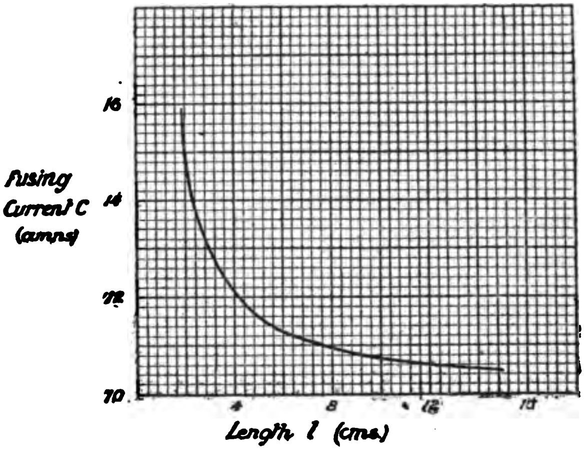

FIG. 86.

Experiment No. M21.—Laws of Induction.

Introduction.—If the strength of the magnetic field about a conductor be altered, or if a conductor be moved through a magnetic field, an E.M.F. is *induced* in that conductor. If this conductor be connected so as to form a complete circuit, a current will be set up due to the E.M.F induced, and the direction of this current, according to Lenz's law, is such that the magnetic field set up by it opposes the variation in the original field. The direction of this induced current is then obviously different for the two cases of an increased and a decreased field, and Lenz's law holds in both cases. A variation in the strength of the magnetic field can be accomplished either by the motion of a permanent magnet, or by the alteration in the field of a neighbouring current-carrying-conductor. This experiment is to follow both these methods, and to verify Lenz's law from the results so obtained.

A. Motion of a Magnet.

Diagram of Connections.—

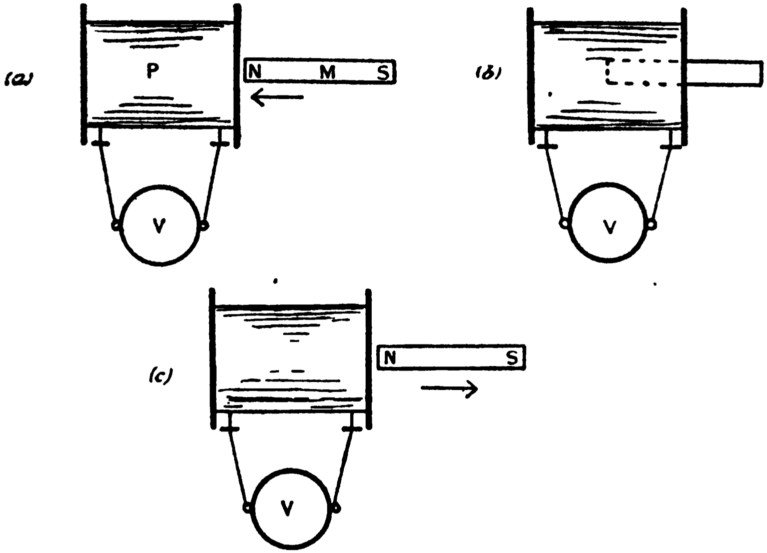

FIG. 87.

Apparatus required.—
P = conductor (say a coil of wire on a bobbin open in the centre).
M = long magnet.
V = low-reading voltmeter (swinging coil, with right and left hand scales).

Method.—(1) Place the coil P away from the influence of any external fields, and connect up as shown with M some distance away.

(2) Suddenly plunge the N. pole of M into one end of the coil, as shown in position *b*, and hold it in that position. Note the amount and the direction of the momentary deflection δ on V. Note the behaviour of V when the magnet is held stationary in the position *b*.

(3) Suddenly withdraw M out of P into the position *c*. Again note the amount and direction of the momentary deflection δ_1. Repeat (2) and (3) a number of times, inserting and withdrawing M at various speeds; tabulate the values and directions of corresponding values of δ and δ_1, and state how δ is affected by the *rate* of moving M.

(4) Test V with a battery, and so find the direction of the induced current in P for each of the above operations.

Results.—Show that the results obtained verify Lenz's law, viz. that the current induced in P in both cases opposes the motion of the magnet M.

B. Alteration of Field in a neighbouring Conductor.

Diagram of Connections.—

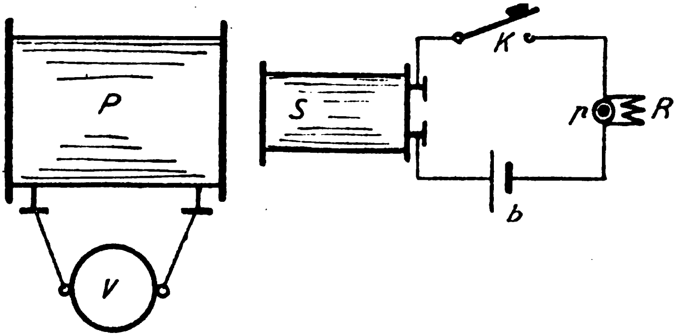

FIG. 88.

Apparatus required.—

P, V = as before.
S = coil to insert in P.
b = cell.
K = key.
p = plug.
R = resistance in parallel with *p*.

Method.—(1) With K open, insert coil S in the middle of coil

P, and insert plug *p* to short-circuit resistance R. Close K and note the momentary deflection δ on V in amount and direction. Note that V is undeflected whilst K remains closed.

(2) Open K, and note δ_1 in value and direction. Repeat a number of times, and tabulate the results obtained.

(3) Unplug *p* and close K, and repeat (1) and (2) by plugging and unplugging *p*, and show that the induced E.M.F. in P is less for a small variation of the field in it.

(4) Repeat operations (1), (2), and (3) with a core of annealed iron wires inserted in S, and show that the magnetic field is greatly increased thereby.

State all the conclusions drawn from the experiments.

Experiment No. M22.—Measurement of Field, Armature, Brush, and Contact Resistances.

Introduction.—The method here employed is that known as the indirect method, and consists simply in measuring the volts drop in the resistance, tested when a known current is passed through it, the resistance being then calculated by Ohm's laws. The method is the usual test-room method for resistances over 0·05 ohms; for resistances below this it is not sufficiently accurate.

A. **Field Resistance.**—The resistance of the copper wire of the field winding depends on its temperature being greater at a higher temperature (*i.e.* after the machine has been running) than at a lower temperature—such, for instance, as it has after standing with unexcited field.* In making a resistance measurement, therefore, the temperature of the winding at the time should be stated. Owing to the impossibility of accurately finding the average temperature of the wire by means of a thermometer, it is obviously best to make the measurement with the coils at the same temperature as the room, *i.e.* after the machine has been standing for at least six hours. Also, since in the method a current of about the same value as the normal field current is used, it is necessary, in order that the coils should not be heated, to make the measurement as quickly as possible consistent with accuracy of measurement of C and E.

These remarks apply also to all measurements of resistance in the machine.

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* See Experiment No. M3 (Variation of R. with Temperature).

Diagram of Connections.—

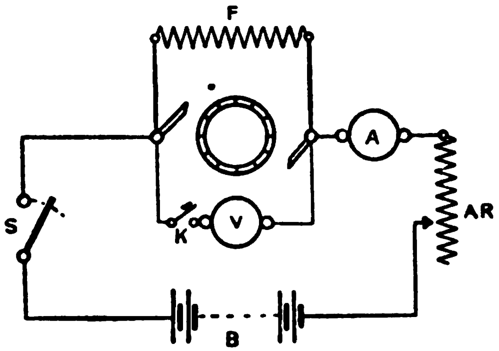

FIG. 89.

Apparatus required.—

F = field-winding of machine.
A = accurate ammeter.
V = accurate voltmeter.
AR = adjustable resistance (such as shunt regulator).
B = source of supply.
S = switch.
K = key in voltmeter circuit.

Method.—(1) Connect up as shown, taking care to raise the brushes from the commutator, and to leave S and K open.

(2) Insert all the resistance in AR, close S, *then* K; take the readings of A and V; open K, and *then* S.*

(3) Take a number of simultaneous readings of C and E for various values of C obtained by adjusting AR, taking care not to heat up the coils by leaving the current switched on.

Results.—Tabulate your results thus:—

I.	II.	III.	IV.
Current through field, Ca.	Voltage drop, E volts.	Resistance of field $R_F = \frac{E}{C}$ ohms.	Remarks.

Find the average value of R_F.

---

* It is of great importance to observe this order of procedure, as with a field having high self-induction, the induced current on breaking S, may damage V if K is left closed.

B. Armature, Brush, and Contact Resistances.

Introduction.—The resistance encountered by a current in the armature portion includes the following:—

(*a*) The resistance of the armature windings.
(*b*) „ „ „ brush contacts.
(*c*) „ „ „ brushes.
(*d*) „ „ „ leads from the brushes to the machine terminals.

In the following measurement it is required to find the value of each of these factors for various armature currents. The most satisfactory method is to measure the voltage drop over portion *a*, then $a + b$, $a + b + c$, and, lastly, $a + b + c + d$, and so from these find the resistances r_a, r_{a+b}, r_{a+b+c}, $r_{a+b+c+d}$.

Diagram of Connections.—

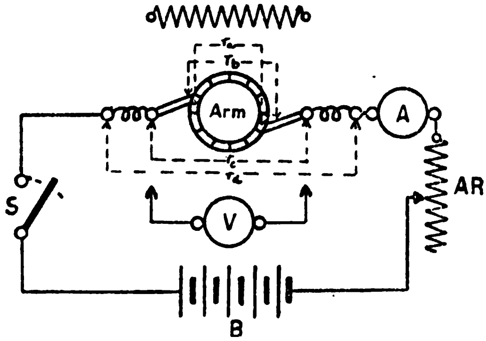

FIG. 90.

Apparatus required.—

Arm. = armature.
A = ammeter to carry full load current.
V = voltmeter (low reading).
B = source of current.
AR = adjustable resistance.
S = switch.

Method.—(1) Bed down the brushes properly, and then rotate the armature through a few revolutions to ensure good brush contact, afterwards bringing it to rest.

(2) Adjust AR for a small current and close S. Note the current C, which must be of exactly the same value for all four measurements *a*, *b*, *c*, and *d*.

(3) Make contact with the voltmeter wires on the ends of the commutator bars in contact with the brushes, and read V_a. Next,

lay them lightly on to the brushes about one-half a cm. from the brush contact with the commutator and read V_b. This measurement is the most important of all, and great care should be taken to lay the voltmeter wires as lightly as possible (consistent with a connection) on the brush tips, so as not to alter the character of the contact by the least amount. In the same manner measure V_c between the joint of the main lead and brush. And, finally, measure V_d between the machine terminals.

(4) Increase C by adjusting AR, and repeat the measurements of V_a, V_b, V_c, and V_d, carefully observing the above precautions and noting their respective values.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Current, C_a	Voltages.				Resistances $\left(=\frac{V}{C}\right)$.				Remarks.
	V_a	V_b	V_c	V_d	R_a	R_b	R_c	R_d	

Plot corresponding values of C and R_a, R_b, R_c, and R_d on the same diagram, taking values of R as ordinates and of C as abscissae.

State what conclusions may be drawn from these curves, and state the values of R armature, R contact, R brushes, and R leads.

Also, given that the probable rise of temperature of the armature and conductors is 50° C., find the following values from the volts and ampères stated on the machine:—

i. Total resistance of armature at full load.

ii. Total watts lost in armature at full load due to ohmic resistance.

iii. Total lost volts in armature at full load due to ohmic resistance.

Results—

RECORD OF EXPERIMENT NO. M22.

(Machine tested—Morley 2 KW shunt.)

A.—*Field Resistance.*

I.	II.	III.	IV.
Current through field, C_a.	Voltage drop, E volts.	Resistance of field, $R_f = \frac{E}{C}$ ohms.	Remarks.
0·826	106·2	128·5	Morley shunt machine, about 2 KW.
1·07	138·1	129·0	
1·394	180·3	129·3	
1·70	219·5	129·0	
		Aver. = 129·0	

B.—*Armature, Brush, and Contact Resistances.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Current, C_a	Voltages.				Resistances $\left(= \frac{V}{C}\right)$.				Remarks.
	V_a	V_b	V_c	V_d	R_a	R_b	R_c	R_d	
1·15	1·85	2·15	Same as V_b.	2·19	1·61	1·87	Same as R_b.	1·90	Same machine as above.
2·2	3·5	3·98		4·02	1·59	1·81		1·83	
3·3	5·28	5·91		5·97	1·60	1·79		1·81	
4·42	7·05	7·86		7·83	1·595	1·78		1·795	
6·8	10·88	12·1		12·25	1·6	1·78		1·8	

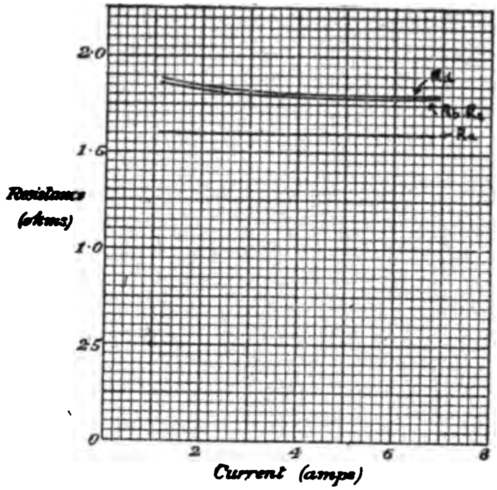

FIG. 91.

Experiment No. M23.—Temperature Measurements on a Machine.

Introduction.—One of the most important points to investigate in a machine is the temperature elevation of the different portions when running under a load. The sources of the heat produced in a machine are numerous. In the field-magnet coils the rise in temperature is caused by the watts lost due to the resistance of the winding; but in the armature a number of effects contribute to heat the machine. With a modern machine the chief cause is the ohmmic resistance encountered by the current in the armature conductors. Another source of heat, although to a much less extent, is the production of eddy currents in the mass of the armature; these are formed in the iron stampings, etc., and are simply very low voltage currents, produced in virtue of the armature mass itself being a conductor cutting lines of force. Their path is made as small as possible by laminating the armature, so that the currents have a path of relatively large resistance presented to their flow. The strength of these eddy currents is therefore reduced, and since the heat produced is proportional to C^2R, the heat produced is much further reduced. Heat is also produced by friction of the brushes on the commutator surface and in the bearings, the former giving rise to an overheated commutator and the latter to hot bearings.

The heat produced by the C^2R loss in the field coils and armature conductors depends on the load, whilst that due to eddy currents and friction is practically the same at all loads. The latter (friction) can be reduced by suitable adjustment of the brushes and lubrication of the bearings.

There are two methods in vogue of measuring the temperature rise in machines:—

A. Directly by a mercury thermometer.

B. Indirectly by measurement of the alteration of resistance of the conductors themselves, or of a special small coil of platinum wire.

For method A the thermometer bulb should be small, and should be wrapped in a small piece of thin tinfoil, placed on the apparatus, and then covered by cotton-wool to prevent loss of heat from the bulb by radiation. This is the simplest method of measuring the rise of temperature; it has, however, a great disadvantage. The temperature of an armature is not uniform throughout, being less at the outside surface than at any other part. Moreover, the relation between the temperatures of the different parts of a machine varies considerably with the design, so that a temperature measured on an external layer of the armature or field-winding gives no accurate idea of the temperatures in other portions of the same member. The following rises of temperature were obtained from a 10 KW motor immediately after running for two hours on full load:—

Armature	maximum temperature (bottom of slots) ...	44° C.
	minimum temperature (end connections) ...	35° C.
Field coils	maximum temperature (layer next to core) ...	50° C.
	minimum temperature (outer layer) ...	36° C.

The temperatures 44° C. and 50° C. were obtained by inserting the thermometer bulb in holes specially drilled in the armature and field respectively.

Method B—the indirect method—is the method most generally employed, and is that explained here. The method consists in finding the resistance of the conductors before and after heating up, and from their increase in resistance calculating the average rise in temperature in the material of the conductors.

Let R_0 = resistance of winding at 0° C.,

R_T = " " T° C.,

$$\text{Then } R_T = R_0 (1 + a\,T)$$

where a (average 0° − 100° C.) is 0·00428 for copper.* a is rightly the amount of its resistance at 0° C., by which a conductor varies for each degree C. variation in temperature. Generally, the initial temperature of the conductors is over 0° C., *i.e.* the temperature of its surroundings.

---

* See Experiment M3 and Table V., Appendix II.

Let T_1 = initial temperature of winding,
R_{T_1} = „ resistance „

$$\text{Then } R_{T_1} = R_0(1 + aT_1),$$
$$\text{and } R_T = R_0(1 + aT),$$

$$\text{from which we get } T_1 = \frac{\left(\frac{R_{T_1}}{R_0} - 1\right)}{a} = 234\left(\frac{R_{T_1}}{R_0} - 1\right) \quad (a = 0{\cdot}00428)$$

$$\text{and } T = \frac{\left(\frac{R_T}{R_0} - 1\right)}{a} = 234\left(\frac{R_T}{R_0} - 1\right),$$

$$\text{so that } T - T_1 = 234\left(\frac{R_T - R_{T_1}}{R_0}\right).$$

$$\text{But } R_0 = \frac{R_{T_1}}{1 + aT_1}.$$

Substituting this value for R_0 in above, we get—

$$\text{rise of temperature} = T - T_1 = 234\left(\frac{R_T - R_{T_1}}{\frac{R_{T_1}}{1 + aT_1}}\right)^\circ \text{C}.$$

An approximate expression used in practice is—

$$T - T_1 = 250\left(\frac{R_T - R_{T_1}}{R_{T_1}}\right)^\circ \text{C}.$$

This gives the *average* rise in temperature in terms of initial and final resistance, and initial temperature of the machine, which is that of the room, and is taken by a thermometer.

The method here described is that which would be followed in what may be termed a "workshop test" by method B; method A is also given so that the results may be compared.

Diagram of Connections.—As for previous experiment.

Apparatus required.—As for previous experiment. Also add two or three accurate thermometers, thin tinfoil, cotton-wool.

Method.—(1) With the machine at room temperature, measure field and armature resistances (see previous experiment). NOTE.—The temperature of the connections of the armature other than the windings themselves has only a small change during the test, so that we consider only the resistance at the commutator.

(2) Start the machine on full load, which must be maintained approximately constant throughout.

(3) At intervals of 15 minutes stop the machine and measure all the resistances as quickly as possible, consistent with accuracy. When this is done, start the machine immediately on full load again.

(4) Repeat (3) for about two hours, allowing no stoppage for measurements of longer than two minutes. After stopping the machine, wrap each thermometer bulb in a little tinfoil, place one on the field winding, one on the armature surface, and one on the commutator surface, cover each bulb with a small pad of cotton-wool, and after two or three minutes note the temperature.

From the formula above, viz.—

$$\text{Rise in degrees C} = 250\left(\frac{R_T - R_{T_1}}{R_{T_1}}\right)$$

find the rise of temperature after a quarter-hour, half-hour, etc., up to two hours.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Initial temperature, T_1° C.	**Initial resistance, R_{T_1} ohms.**	**Time from start, *t*.**	**Resistance at T° C., R_T ohms.**	**Rise of temperature, $(T - T_1)$° C.**	**Remarks.**
					Armature **Field** **Positions of thermometers and readings_____**

Plot curves showing the relation between rise of temperature and time for both armature and field.

Also, compare the temperatures given by the thermometers with the temperatures calculated above. State what conclusions you draw from the curves.

Results—

RECORD OF EXPERIMENT NO. M23.

(Machine tested—Morley 2 KW Shunt.)

I.	II.	III.	IV.	V.	VI.
Initial temperature, T_1° C.	Initial resistance, R_{T_1} ohms.	Time from start.	Resistance at T° C., R_T ohms.	Rise of temperature, $(T - T_1)$° C.	Remarks.
		hours.	ohms.	°C.	
15° C.	2·08	0	—	—	Armature.
		$\frac{1}{4}$	2·18	19	
		$\frac{1}{2}$	2·27	31·5	
		$\frac{3}{4}$	2·35	37	
		1	2·41	44	
		$1\frac{1}{4}$	2·45	48	
		$1\frac{1}{2}$	2·485	52	
		$1\frac{3}{4}$	2·5	54	
		2	2·51	55	
15° C.	129	—	—	—	Field.
		$\frac{1}{4}$	140	21	
		$\frac{1}{2}$	146	34	
		$\frac{3}{4}$	151	43	
		1	153	47·5	
		$1\frac{1}{4}$	156	53	
		$1\frac{1}{2}$	157	55·5	
		$1\frac{3}{4}$	158	59	
		2	158·5	60·5	

Note.—The student who made the above experiment assumed $a = 0{\cdot}004$, from which he obtained the expression—

$$\text{Rise of temperature} = 250\left(\frac{\frac{R_T - R_{T1}}{R_{T1}}}{1 + aT_1}\right)^{\circ}\text{ C.}$$

This corresponds to an approximate formula—

$$\text{Rise} = 265\left(\frac{R_T - R_{T1}}{R_{T1}}\right)^{\circ}\text{ C.}$$

The values given in column V. above are therefore about 6 per cent. higher than they should be.

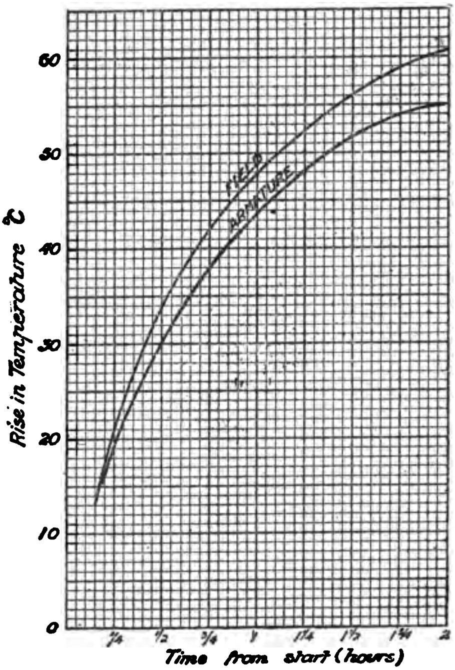

FIG. 92.

Experiment No. M24.—The Shunt Dynamo: No-Load Characteristic with Separate Excitation.

Introduction.—This experiment is to find how the E.M.F. of a dynamo varies with the current supplied to its field, the speed of the machine being maintained constant throughout. Since the machine supplies practically no current, the E.M.F. generated in its armature will be that indicated by a voltmeter connected across its terminals. The dynamo to be tested is driven by a motor having a regulating resistance in its field so that the speed can be maintained constant throughout.

In such a dynamo the E.M.F., E, of the armature is given by the equation—

$$E = \frac{Z \,.\, n \,.\, N}{60 \,.\, 10^8} \,.\, \frac{p}{p_1},$$

where Z = number of armature conductors (useful),
n = R.P.M.,
N = total flux through the armature,
p = number of *pairs* of poles,
p_1 = number of *pairs* of parallel circuits in the armature.

For the machine tested the factors Z, p, p_1, and if the speed is maintained constant n also, are constant throughout the experiment, so that—

$$E = K . N.$$

where K is some constant.

From this it is seen that the relation between the exciting current and E also represents the relation between the exciting current and the total flux produced by the field ampère turns, *i.e.* the curve between C_8 and E represents the "Magnetisation Curve" of the machine.

Diagram of Connections.—

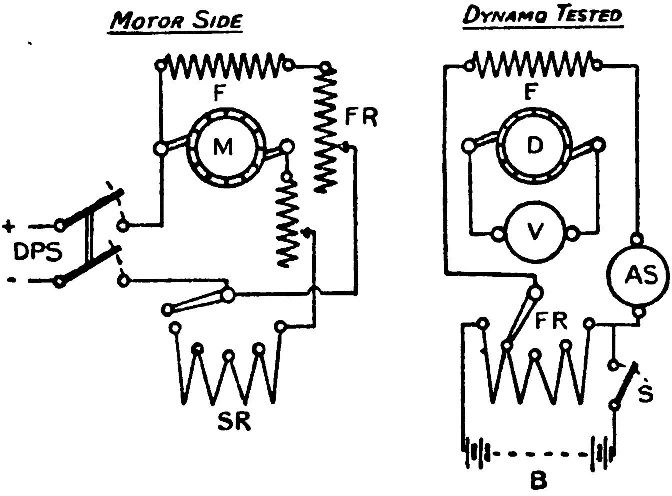

FIG. 93.

Apparatus required.—

M, D = armatures of motor and dynamo respectively.
F, F = fields.
FR, FR = field resistances.
SR, R = starter and resistance for motor.
V = voltmeter on dynamo armature.
+ – = source of supply to motor.
A_8 = ammeter in dynamo field.
B = source of steady current to dynamo field.
DPS, S = switches on motor and dynamo.
A tachometer.

Method.—(1) With S open start the machine, and by means of FR on the motor adjust to normal speed; place the brushes of the dynamo in the neutral position. Note the volts indicated on V. This E.M.F. is due to the armature rotating in the residual field of the machine, and is called the "residual voltage."

(2) Adjust FR on D for a small exciting voltage and current C_s; close S. Adjust the speed to normal, and note the value of E on V and of C_s on A_s.

(3) Without opening S increase C_s, adjust to speed, and note values of C_s and E.

(4) Repeat (3) for increasing values of C_s up to about 50 per cent. above normal exciting current (if voltage of B is sufficient). Note corresponding values of C_s and E.

(5) Without opening S, repeat (3) and (4) for decreasing values of C_s. Finally, open S and again measure the residual voltage.

Note.—It often happens that the motor cannot be arranged to give the normal speed of the dynamo, in which case the values of E taken alone will have to be corrected. From the formula stated above it is seen that E is directly in proportion to n—the R.P.M. Hence if—

n = normal speed,
n_1 = actual speed,
E_1 = actual volts measured on V,

$$\text{Then } E = E_1\frac{n}{n_1},$$

where E is the correct voltage at speed n.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Exciting current, C_s.	Terminal voltage, E_1.	Actual R.P.M., n_1.	Normal R.P.M., n.	Corrected voltage, E.	Remarks.
					Ascending values of C_s.
					Descending values of C_s.

Plot a curve showing the relation between E and both ascending and descending values of C_s, plotting values of E as ordinates.

Explain why these curves do not coincide. Draw the average curve of the two; then this average curve is the magnetisation curve of the machine.

Results—

RECORD OF EXPERIMENT No. M24.

(Machine tested—Morley 2 KW shunt.)

I.	II.	III.	IV.	V.	VI.
Exciting current, C_s.	Terminal voltage, E_1.	Actual R.P.M., n_1.	Normal R.P.M., n.	Corrected voltage, E.	Remarks.
0·22	40·4	1720	1700	40	Ascending values of C_s.
0·40	76·3	1730	,,	72·3	
0·64	110	1730	,,	108·2	
0·83	137·4	1680	,,	139	
1	162	1700	,,	162	
1·14	177·6	1700	,,	177·6	
1·32	190	1640	,,	197	
1·48	196·8	1600	,,	209	
1·7	232	1760	,,	224·5	
1·32	200	1700	,,	200	Descending values of C_s.
1·13	183·2	1740	,,	179	
1	169	1750	,,	164·2	
0·77	132·4	1700	,,	132·4	
0·53	96	1700	,,	96	
0·3	57·2	1760	,,	55·3	

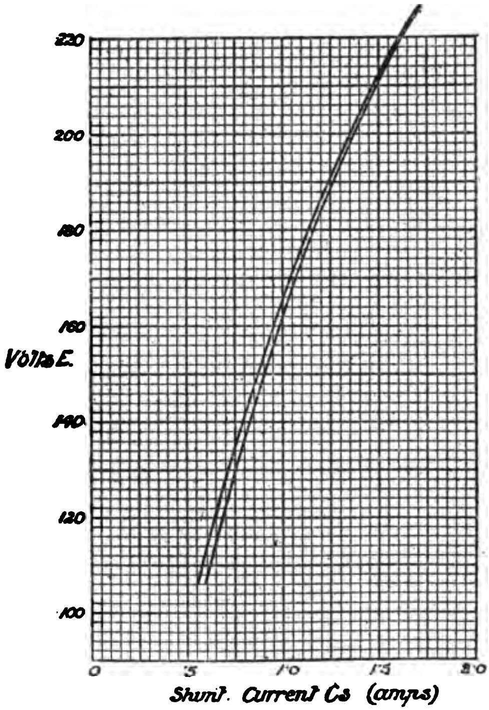

FIG. 94.

Experiment No. M25.—The Shunt Dynamo: No-Load Characteristic with Constant Excitation.

Introduction.—This experiment is to find how the E.M.F. of an unloaded machine varies with its speed, the excitation remaining constant. The machine tested is driven by an auxiliary motor, whose speed can be varied within wide limits, from 20 per cent. up to 120 per cent. normal speed, or even more for a small machine.

Diagram of Connections.—

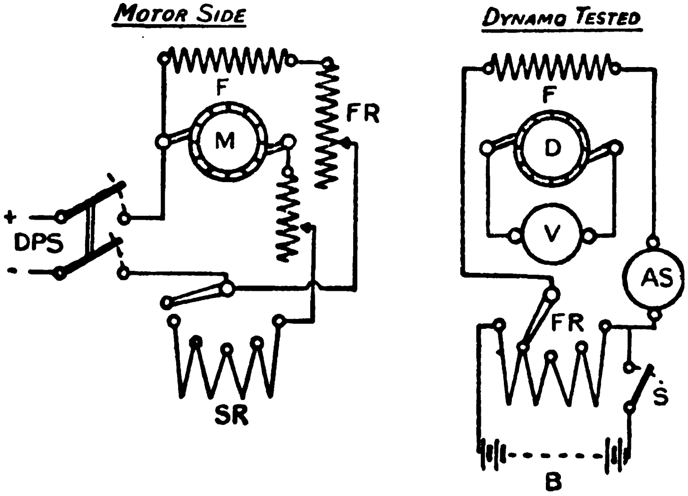

Fig. 95.

Apparatus required.—

M, D = armatures of motor and dynamo respectively.
F, F = fields " " " " "
FR, FR = field regulators " " "
SR, R = starter and resistance for motor.
A_s = ammeter in dynamo field.
V = voltmeter on dynamo armature.
+ − = source of motor supply.
B = source of constant current.
DPS, S = switches.
Tachometer.

Method.—(1) With dynamo field circuit open, run motor at a low speed; note R.P.M. and voltage indicated on V. Increase the speed, and take the new value of E indicated on V. Repeat for increasing values of R.P.M. up to about 25 per cent. above normal, taking four or five sets of readings in all. These values of E are residual voltages at their respective speeds.

(2) Close S, and adjust the shunt current indicated on A to about 25 per cent. normal exciting current, and keep this constant for this series of readings. Repeat (1) for increasing speeds, noting corresponding values of R.P.M. and E in each case.

(3) Increase C_1 to 0·5 normal, momentarily break circuit by S, and repeat.

(4) Repeat for values of C_s 0·75, 1, and 1·25 normal, keeping these values constant throughout their series, and noting accurately corresponding values of E and R.P.M.

Results.—Tabulate your results thus—

I.	II.	III.	IV.
Exciting current, C_s.	**E.M.F., E.**	**Speed, R.P.M.**	**Remarks.**

Plot curves showing the relation between E and R.P.M. for each value of exciting current, taking values of E as ordinates and of speed as abscissæ.

State what you conclude from the shape of these curves.

Results—

Record of Experiment No. M25.

(Machine tested—Morley 2 KW shunt.)

I.	II.	III.	I.	II.	III.
Exciting or shunt current C_s.	**Voltage, V.**	**Speed, R.P.M.**	**Exciting or shunt current C_s.**	**Voltage, V.**	**Speed, R.P.M.**
amp.	volts.		amp.	volts.	
0	0·45	420	1·2	45	410
0	0·65	600	1·2	64	580
0	0·86	785	1·2	110	1000
0	1·4	1300	1·2	174	1580
0	1·75	1620	1·2	220	1800
0	2	1840			

RECORD OF EXPERIMENT NO. M25—*continued.*

I.	II.	III.	I.	II.	III.
Exciting or shunt current C_s.	**Voltage, V.**	**Speed, R.P.M.**	**Exciting or shunt current C_s:**	**Voltage, V.**	**Speed, R.P.M.**
amp.	volts.		amp.	volts.	
0·3	14·6	490	1·5	62	480
0·3	21	690	1·5	108	850
0·3	24·5	800	1·5	226	1800
0·3	30·5	990			
0·3	47·5	1530			
0·3	57	1850			
0·9	47	535	0·6	38	650
0·9	58	665	0·6	66·4	1120
0·9	87	990	0·6	106·4	1780
0·9	109	1240			
0·9	140	1600			
0·9	155	1780			

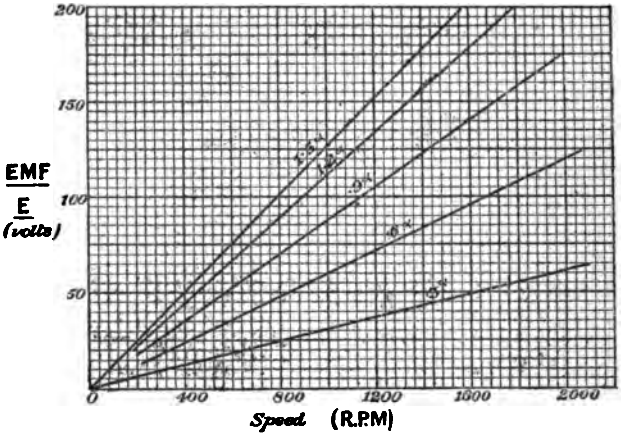

FIG. 96.

Experiment No. M26.—The Shunt Motor. No-Load: Characteristic.—Shunt Current and Speed.

Introduction.—The object is to find how the speed of a shunt motor varies with the shunt current, the machine being unloaded. In a previous experiment (M24) it was stated that the E.M.F. of a dynamo was given by the equations—

$$E = \frac{Z \cdot n \cdot N}{60 \times 10^8} \cdot \frac{p}{p_1},$$

where Z = number of armature conductors (useful),
n = R.P.M.,
N = total flow through the armature,
p = number of *pairs* of poles,
p_1 = number of *pairs* of parallel circuits in the armature.

In the motor under test the load and the E.M.F. of the motor are practically constant, so that we can write—

$$n = \frac{E \cdot 60 \cdot 10^8}{ZN} \cdot \frac{p_1}{p}.$$

In this expression the factors Z, p, p_1, and E (above) are constant, so that—

$$n = \frac{K}{N}$$

where K is some constant.

Also, N is some function of the exciting or shunt current C_s, so that

$$n \propto \frac{1}{C_s}.$$

From this it is seen that if C_s is decreased the speed of the motor is increased, and *vice versâ;* if the shunt current is reduced to zero theoretically, the armature would attain an infinite speed. The inference to be drawn from this is obvious—never attempt to start a motor without first ensuring that a strong field is provided.

Diagram of Connections.—

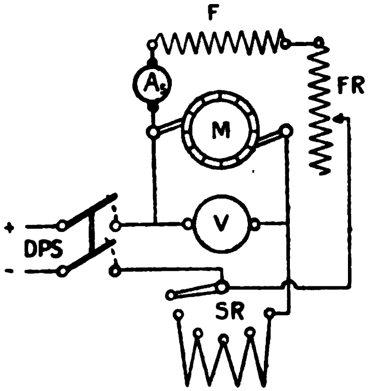

FIG. 97.

Apparatus required.—

M = armature of motor.
F = field of motor.
FR = field resistance.
SR = starting resistance.
A_s = ammeter in shunt.
V = voltmeter on armature.
DPS = double pole switch.
+ − = source of steady supply.
A tachometer.

Method.—(1) With SR open, close DPS, and by cutting out all the resistance in FR, supply the field with maximum excitation. Place the brushes in the neutral position, and start the motor by SR until V indicates that the armature is supplied with its normal voltage. Note the speed n and the exciting current C_s. In taking n, find the average of a number of, say 3, readings.

(2) Decrease FR, thus slightly increasing C_s; when the machine has attained a steady speed, note the new values of C_s and n.

(3) Repeat (2) over a large range of C_s until the maximum allowable speed is obtained on the motor. For ordinary armatures of good mechanical construction the maximum allowable peripheral speed of the armature surface is about 80 feet per second. To find the maximum allowable RPM—

Let D = diameter of armature in feet,
n = maximum allowable RPM,

$$\text{Then } \frac{\pi D n}{60} = 80$$

$$\text{so that } n = \frac{1500}{D} \text{ RPM (approximately)}$$

(4) Repeat for increasing values of C_s, carefully noting corresponding values of C_s and *n*.

Results.—Tabulate your results thus:—

I.	II.	III.	IV.
Volts on armature, E.	Exciting current, C_s.	Speed R.P.M., *n*.	Remarks.
			C_s decreasing.
			C_s increasing.

Plot two curves between C_s and *n* for decreasing and increasing values of C_s, taking values of *n* as ordinates.

These curves will not exactly coincide, being similar in this respect to those obtained in Experiment M24. Plot the average curve, and state what conclusions can be drawn from it.

Results—

RECORD OF EXPERIMENT No. M26.

(Machine tested—Morley 2 KW shunt.)

I.	II.	III.	IV.
Volts on armature, E.	Exciting current, C_s.	Speed R.P.M., *n*.	Remarks.
220	1·69	1630	C_s decreasing.
”	1·63	1655	
”	1·58	1675	
”	1·49	1710	
”	1·4	1750	
”	1·3	1810	
”	1·2	1900	
”	1·1	2000	

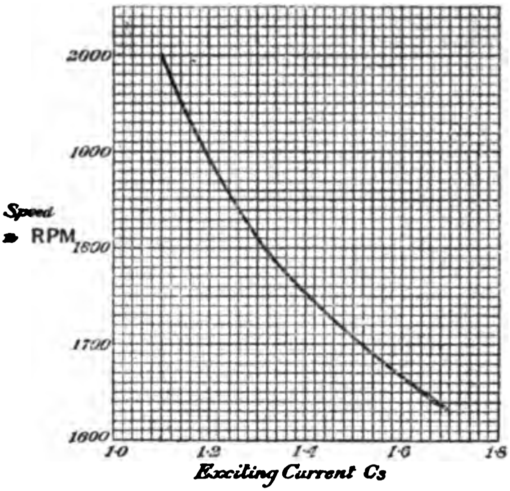

FIG. 98.

Experiment No. M27.—Potential Curve of a Dynamo.

Introduction.—If a study be made of an ordinary armature in which all the conductors on either side of the brushes are in series, and the two sections in parallel with one another, it will be found that all the conductors connected in series add their E.M.F.'s together to give that of the machine. Consider the following simple ring armature, in which half the total conductors are in parallel with the other half:—

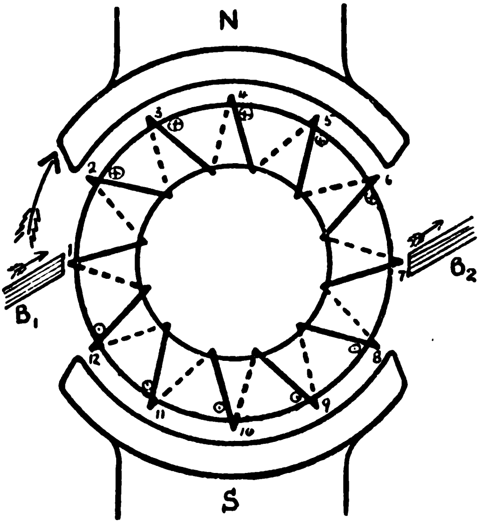

FIG. 99.

Wires 2, 3, 4, 5, and 6 are all under the influence of the north pole; they have therefore all their E.M.F.'s induced away from the reader ⊗, and it is seen that all their E.M.F.'s are added together so that the E.M.F. between the brushes B_1 and B_2 is equal to their sum. Similarly wires 8, 9, 10, 11, and 12 are under the influence of the south pole, and all their E.M.F.'s are induced in a direction towards the reader ⊙. All are added together to give the total E.M.F. between B_1 and B_2. Thus the two halves of the armature are in parallel, and produce an E.M.F. which makes B_2 positive and B_1 negative. In an actual machine, the small E.M.F.'s induced in the various conductors are not of the same value, because, since all are moving at exactly the same speed, each small E.M.F. is proportional to the field it is passing through at the time; and this field is not uniform over the whole armature surface. The actual manner in which the separate conductors contribute to the total E.M.F. is of great importance, since their respective amounts afford an indication of the strength of field in their respective positions.

This experiment is to find how the E.M.F. between the two brushes B_1 and B_2 is built up by the conductors between them, and the method employed is to measure the potential difference between 1 and 2, 1 and 3, 1 and 4, etc., until, finally, the full E.M.F. is given between 1 and 7. The difference between two consecutive readings gives the E.M.F induced in the last included conductor, *e.g.* 1 and 2 gives E_1, 1 and 3 gives E_2; then the E.M.F. contributed by conductor 3 is clearly $E_2 - E_1$, and $E_2 - E_1$ represents the strength of field it is passing through. By subtracting these consecutive readings of E, values are obtained representing the strength of field at the different points under the pole faces; and if these values are plotted vertically at regular intervals representing commutator segments, the resulting curve represents the "field distribution." Values of E_1, E_2, etc., plotted similarly, give the "potential curve" of the machine.

Diagram of Connections.—

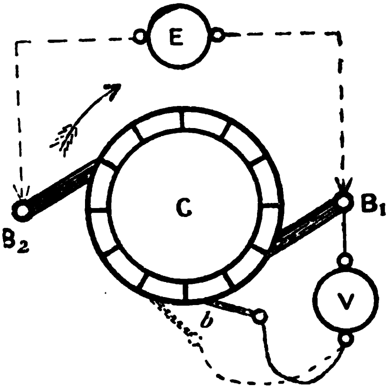

FIG. 100.

Apparatus required.—

A dynamo which can be run by a motor at constant speed, and provided with a shunt regulator, so that the main voltage indicated on E can be maintained constant.

C = commutator of dynamo tested.
B_1, B_2 = brushes „ „
V = testing voltmeter.
b = auxiliary brush so arranged that it can be placed on consecutive commutator bars.

Method.—(1) Run the machine up to normal speed; adjust B_1 and B_2 to the neutral position, and adjust the field current to give normal voltage on E. These conditions must be maintained throughout.

(2) Connect up V and place *b* at a distance of one commutator bar away from B_1. Note the voltage E_1 given on V, and the number of commutator bars between *b* and B_1.

(3) Move *b* over another commutator segment away from B_1 and repeat.*

(4) Repeat until *b* is on B_2, when V indicates the full voltage. Note in each case the E.M.F. E and the number of commutator bars over which it is taken.

Results.—Tabulate your results thus—

I.	II.	III.	IV.	V.	VI.
Speed, R.P.M.	Voltage, B_1 to B_2.	Voltage on V, E.	Commutator bars, B_1 to $b = n$.	Increments of E per commutator bar (from curve).	Remarks.

Plot a "potential curve" between values of E and Column IV., taking values of E for ordinates.

Plot a "field distribution curve" between values in Column V. and Column IV.

(Note that values in Column V. are taken from the "potential curve.")

Draw the probable position of the pole face above this curve, and state your conclusions from the experiment.

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* It may be necessary to stop the machine momentarily to get the correct position for *b* as *n* increases. Care should be taken not to alter the shunt current, and to obtain the correct R.P.M. again.

Results—

RECORD OF EXPERIMENT NO. M27.

(Machine tested—Morley 2 KW shunt.)

I.	II.	III.		IV.	V.	VI.
Speed, R.P.M.	Voltage, B_1 to B_2.	Voltage on V, E.		Commutator bars, B_1 to $b = n$.	Increments of E per commutator bar (from curve).	Remarks.
1700	183	0	0	0	0	
„	„	1·5	1·5	4	1·5	
„	„	6	6	6	4·5	
„	„	15	21	8	15	
„	„	50	45	10	24	
„	„	72	72	12	27	
„	„	99	99	14	27	
„	„	125	127	16	28	
„	„	156	155	18	28	
„	„	175	175	20	20	
„	„	185	185	22	10	
„	„	183	183	24	−2	Brush.
			from curve			

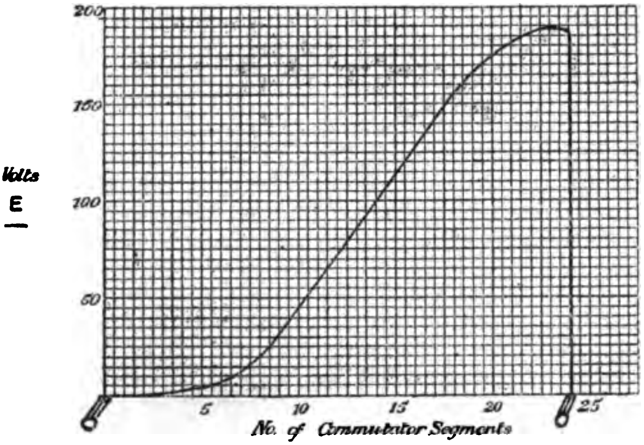

FIG. 101.

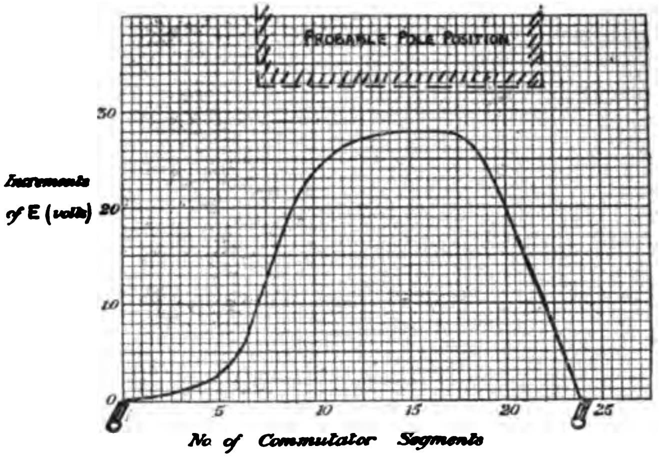

Fig. 102.

Experiment No. M28.—Magnetic Measurements on a Dynamo.

Introduction.—In a dynamo a certain portion of the field produced in the magnetizing coils is lost, and does not pass through the armature core. The amount of this "leakage" or "stray" depends on the type, size, and form of the machine, and will, for a given machine, be greater with a greater induction. The ratio of the total number of lines produced by the field to those passing usefully through the armature is called the "stray coefficient;" this stray coefficient will, of course, always be greater than unity. The object of this experiment is to find the value of the stray coefficient of a machine under full or normal excitation. The method here employed is based upon the fact that an E.M.F. is induced in coil by any variation of the field it encloses, and this E.M.F. is equal in amount to the "rate of change of field" and number of turns in the coil. If, therefore, a coil be wound to enclose any portion of the magnetic circuit of the machine, and a sudden small alteration be made in the strength of that field, a momentary E.M.F. will be generated in the coil which can be utilized to deflect a voltmeter. If the same coil, or a second coil having the same number of turns, be wound to enclose another portion of the same magnetic circuit, then an E.M.F. will be induced in this also, and the ratio of this E.M.F. to that of the first coil represents the ratio of the alteration of field in them, other conditions being the same in both cases. Further, if these two coils be connected through a very low-reading ammeter so that their

E.M.F.'s E_1, and E_2 oppose each other, the ammeter will deflect if E_1 is not equal to E_2. If the ammeter is undisturbed when the magnetic field through both is suddenly changed, then $E_1 = E_2$. This result can be attained by adjusting the number of turns in the coils until on altering the field no deflection is seen on the ammeter when $E_1 = E_2$.

Let N_1 = change in the number of lines through coil 1,
N_2 = " " " " 2,
S_1 = number of turns in coil 1,
S_2 = " " " 2,
Then, since E_1 = rate of change of lines in coil 1,
E_2 = " " " " 2,

$$\frac{N_1 . S_1}{t} = \frac{N_2 . S_2}{t},$$

where t = time of change of field;

$$\text{so that } \frac{N_2}{N_1} = \frac{S_1}{S_2}.$$

If the change in field is small so that the stray coefficient is unaltered (note remark above, that the stray coefficient is less for lower and greater for higher inductions), the values N_1 and N_2 represent the *total* flux through their respective coils; so that if coil 1 embraced the armature, and coil 2 a field coil, the stray coefficient is given by—

$$\frac{N_2}{N_1} \text{ or } \frac{S_1}{S_2}.$$

This differential method is due to Goldschmidt, and is the easiest way of obtaining the coefficient of a machine.

Diagram of Connections.—

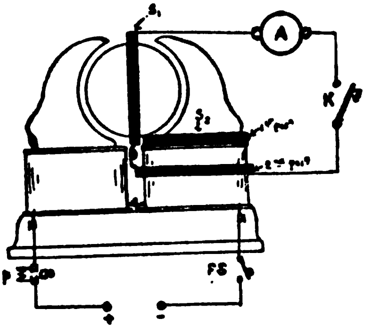

FIG. 103.

Apparatus required.—

S_1, S_2 = two coils, the number of turns of one of which can be varied, say S_1.
$+$ $-$ = source of steady E.M.F. sufficient to give normal excitation to field.
p = plug-switch for suddenly inserting resistance r.
A = milliameter.
K = key in circuit of A.
FS = main field circuit switch.

Method.—(1) Place S_1 and S_2 in position, making S_1 of sufficient size to enclose all the lines passing through the armature core. If the armature is a ring armature, this is best accomplished by winding the coil over one side of the ring in a position between the poles, when it encloses one-half the purely useful lines through the armature core.

(2) Open K, insert p, and *then* close FS, so that the field magnets are fully excited. Now close K and suddenly unplug p, so that the shunt current is decreased slightly and the field increased by the introduction of a small resistance r of about ·02 of the field resistance. Note the sudden kick of A, and then open K and insert p.

(3) Alter the number of turns S_1 in coil 1 until on repeating (2) no deflection is obtained on A. If the exact conditions, *i.e.* the exact number of turns S_1, cannot be obtained, two values, one just too large and the other just too small, should be obtained, and the correct S_1 estimated from their respective kicks, which will be in opposite directions. In these tests carefully observe the procedure given in (2), as if it is not followed step by step the ammeter A may be damaged by an excessive kick.

Results.—Tabulate your results thus—

I.	II.	III.	IV.		V.	VI.	VII.
Exciting current, C_s.	Turns on coil 2, S_2.	Turns on coil 1, S_1.	Throw on A		Correct, S_1.	Stray coefficient, $\frac{S_1}{S_2}$	Remarks.
			to left.	to right.			

Repeat the experiment for a reduced value of exciting current, and show that for smaller inductions the coefficient is decreased.

Results—

RECORD OF EXPERIMENT No. M28.

(Machine tested—Morley machine, 2 pole, over-type, about 2 KW.)

I.	II.	III.	IV.		V.	VI.	VII.
Exciting current, C_s.	Turns on coil 2, S_2.	Turns on coil 1, S_1.	Throw on A		Correct, S_1.	Stray coefficient, $\frac{S_1}{S_2}$	Remarks.
			to left.	to right.			
1·5	50	67	20°	—	67·5	1·35	2nd position of S_2.
1·5	50	68	—	18°			
1·0	50	65	30°	—	65	1·30	
1·0	50	65	30°	—			
0·5	50	64	—	2°	64	1·28	
0·5	50	64	—	2°			
1·5	50	58	—	16°	57·5	1·15	1st position of S_2.
1·5	50	57	16°	—			
1·0	50	56	2°	—	56	1·12	
1·0	50	56	2°	—			
0·5	50	55	—	3°	55	1·10	
0·5	50	55	—	2·5°			

APPENDIX I

No. 1.—Manufacture of the Clark Standard Cell.

THE IMPERIAL OHM, AMPÈRE, AND VOLT.

[*] At the Court at Osborne House, Isle of Wight, the 23rd day of August, 1894.

Present, the Queen's Most Excellent Majesty in Council.

Whereas by "The Weights and Measures Act, 1889," it is among other things enacted that the Board of Trade shall from time to time cause such new denominations of standards for the measurement of electricity as appear to them to be required for use in trade to be made and duly verified.

And whereas it has been made to appear to the Board of Trade that the new denominations of standards are required for use in trade based upon the following units of electrical measurement, viz.:—

1. The Ohm, which has the value 10^9 in terms of the centimetre and the second of time, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14·4521 grammes in mass of a constant cross-sectional area, and of a length of 106·3 centimetres.

2. The Ampère, which has the value $\frac{1}{10}$ in terms of the centimetre, the gramme, and the second of time, and which is represented by the unvarying electric current which, when passed through a solution of nitrate of silver in water in accordance with the specification appended hereto and marked A, deposits silver at the rate of 0·001118 of a gramme per second.

3. The Volt, which has the value 10^8 in terms of the centimetre, the gramme, and the second of time, being the electrical pressure that if steadily applied to a conductor whose resistance is one ohm will produce a current of one ampère, and which is represented by 0·6974 ($\frac{1000}{1434}$) of the electrical pressure at a temperature of 15° C. between the poles of the voltaic cell, known as Clark's cell, set up in accordance with the specification appended hereto, and marked B.

And whereas they have caused the said new denominations of standards to be made and duly verified.

Now, therefore, Her Majesty, by virtue of the power vested in Her

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[*] From the *London Gazette* of Friday, August 24, 1894.

by the said Act, by and with the advice of Her Privy Council, is pleased to approve the several denominations of standards set forth in the schedule hereto as new denominations of standards for electrical measurement.
C. L. Peel.

SCHEDULE.

I.—Standard of Electrical Resistance.

A standard of electrical resistance denominated one ohm, being the resistance between the copper terminals of the instrument marked "Board of Trade Ohm Standard Verified 1894" to the passage of an unvarying electrical current when the coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of 15·4° C.

II.—Standard of Electrical Current.

A standard of electrical current denominated one ampère, being the current which is passing in and through the coils of wire forming part of the instrument marked "Board of Trade Ampère Standard Verified 1894" when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridio-platinum weight marked A and forming part of the said instrument.

III.—Standard of Electrical Pressure.

A standard of electrical pressure denominated one volt being one-hundredth part of the pressure which, when applied between the terminals forming part of the instrument marked "Board of Trade Volt Standard Verified 1894," causes that rotation of the suspended portion of the instrument which is exactly measured by the coincidence of the sighting wire with the image of the fiducial mark A before and after application of the pressure, and with that of the fiducial mark B during the application of the pressure, these images being produced by the suspended mirror and observed by means of the eyepiece.

In the use of the above standards the limits of accuracy attainable are as follows:—

For the ohm, within one-hundredth part of 1 per cent.

For the ampère, within one-tenth part of 1 per cent.

For the volt, within one-tenth part of 1 per cent.

The coils and instruments referred to in this schedule are deposited at the Board of Trade Standardising Laboratory, 8, Richmond-terrace, Whitehall, London.

Specifications referred to in the foregoing Order in Council:—

SPECIFICATION A.

In the following specification the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time the time average of the current, or if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about one ampère the following arrangements should be adopted. The cathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 cm. in diameter, and from 4 cm. to 5 cm. in depth.

The anode should be a plate of pure silver some 30 sq. cm. in area and 2 mm. or 3 mm. in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the cathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a Measurement.

The platinum bowl is washed with nitric acid and distilled water, dried by heat, and then left to cool in a desiccator. When thoroughly dry it is weighed carefully.

It is nearly filled with the solution, and connected to the rest of the circuit by being placed on a clean copper support to which a binding screw is attached. This copper support must be insulated.

The anode is then immersed in the solution so as to be well covered by it and supported in that position; the connections to the rest of the circuit are made.

Contact is made at the key, noting the time of contact. The current is allowed to pass for not less than half an hour, and the time at which contact is broken is observed. Care must be taken that the clock used is keeping correct time during this interval.

The solution is now removed from the bowl, and the deposit is washed with distilled water and left to soak for at least six hours. It is then rinsed successively with distilled water and absolute alcohol, and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is weighed again. The gain in weight gives the silver deposited.

To find the current in ampères, this weight, expressed in grammes, must be divided by the number of seconds during which the current has been passed, and by 0·001118.

The result will be the time-average of the current, if during the interval the current has varied.

In determining by this method the constant of an instrument the current should be kept as nearly constant as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time-average of the current) can be found. The current, as calculated by the voltameter, corresponds to this reading.

SPECIFICATION B.

On the Preparation of the Clark Cell.

Definition of the Cell.

The cell consists of zinc or an amalgam of zinc with mercury and of mercury in a neutral saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess.

Preparation of the Materials.

1. *The Mercury.*—To secure purity it should be first treated with acid in the usual manner, and subsequently distilled in vacuo.

2. *The Zinc.*—Take a portion of a rod of pure redistilled zinc, solder to one end a piece of copper wire, clean the whole with glass paper or a steel burnisher, carefully removing any loose pieces of the zinc. Just before making up the cell dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

3. *The Mercurous Sulphate.*—Take mercurous sulphate, purchased as pure, mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water, and repeat the process at least twice. After the last washing, drain off as much of the water as possible.

4. *The Zinc Sulphate Solution.*—Prepare a *neutral* saturated solution of pure ("pure recrystallized") zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding zinc oxide in the proportion of about 2 per cent. by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised should not exceed 30° C. Mercurous sulphate treated as described in 3 should be added in the proportion of about 12 per cent. by weight of the zinc sulphate crystals to neutralize any free oxide

remaining, and the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. *The Mercurous Sulphate and Zinc Sulphate Paste.*—Mix the washed mercurous sulphate with the zinc sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to insure saturation, and a small quantity of pure mercury. Shake these up well together to form a paste of the consistence of cream. Heat the paste, but not above a temperature of 30° C. Keep the paste for an hour at this temperature, agitating it from time to time, then allow it to cool; continue to shake it occasionally while it is cooling. Crystals of zinc sulphate should then be distinctly visible, and should be distributed throughout the mass; if this is not the case add more crystals from the stock bottle, and repeat the whole process.

This method insures the formation of a saturated solution of zinc and mercurous sulphates in water.

To set up the Cell.

The cell may conveniently be set up in a small test tube of about 2 cm. diameter, and 4 cm. or 5 cm. deep. Place the mercury in the bottom of this tube, filling it to a depth of, say, 0·5 cm. Cut a cork about 0·5 cm. thick to fit the tube; at one side of the cork bore a hole through which the zinc rod can pass tightly; at the other side bore another hole for the glass tube which covers the platinum wire; at the edge of the cork cut a nick through which the air can pass when the cork is pushed into the tube. Wash the cork thoroughly with warm water, and leave it to soak in water for some hours before use. Pass the zinc rod about 1 cm. through the cork.

Contact is made with the mercury by means of a platinum wire about No. 22 gauge. This is protected from contact with the other materials of the cell by being sealed into a glass tube. The ends of the wire project from the ends of the tube; one end forms the terminal, the other end and a portion of the glass tube dip into the mercury.

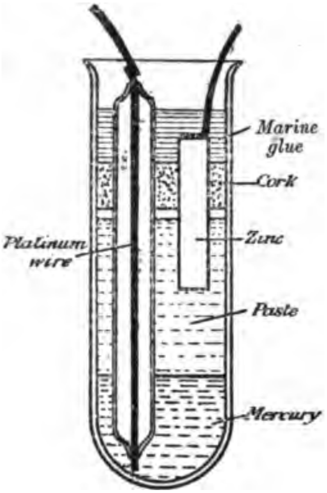
Clean the glass tube and platinum wire carefully, then heat the exposed end of the platinum red-hot, and insert it in the mercury in the test tube, taking care that the whole of the exposed platinum is covered.

Shake up the paste and introduce it without contact with the upper part of the walls of the test tube, filling the tube above the mercury to a depth of rather more than 1 cm.

Then insert the cork and zinc rod, passing the glass tube through the hole prepared for it. Push the cork gently down until its lower surface is nearly in contact with the liquid. The air will thus be nearly all expelled, and the cell should be left in this condition for at least 24 hours before sealing, which should be done as follows:—

Melt some marine glue until it is fluid enough to pour by its own weight, and pour it into the test tube above the cork, using sufficient to cover completely the zinc and soldering. The glass tube containing the platinum wire should project some way above the top of the marine glue.

The cell may be sealed in a more permanent manner by coating the marine glue, when it is set, with a solution of sodium silicate, and leaving it to harden.



BOARD of TRADE FORM of CLARK CELL

FIG. 104.

The cell thus set up may be mounted in any desirable manner. It is convenient to arrange the mounting so that the cell may be immersed in a water bath up to the level of, say, the upper surface of the cork. Its temperature can then be determined more accurately than is possible when the cell is in air.

In using the cell sudden variations of temperature should as far as possible be avoided.

The form of the vessel containing the cell may be varied. In the H form, the zinc is replaced by an amalgam of 10 parts by weight of zinc to 90 of mercury. The other materials should be prepared as already described. Contact is made with the amalgam in one leg of the cell, and with the mercury in the other, by means of platinum wires sealed through the glass.

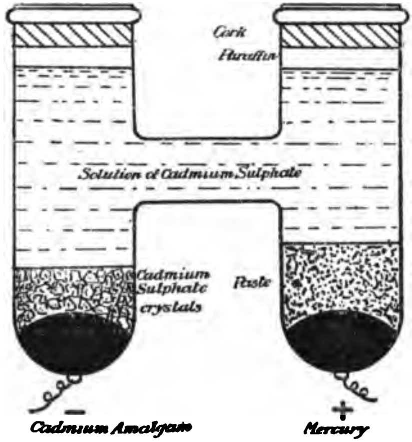
No. 2.—The Reichsanstalt Form of Cadmium Cell.

This cell is due originally to Mr. Weston, who recognized the advantages it possesses on account of its great reliability and small temperature coefficient (see below, and Appendix II. for that of the Clark and Carhart Clark Standard Cells). The cell has been investigated very fully by Professor W. Jaegar of the Physikalisch-Technische Reichsanstalt, who, after many experiments, recommends that the cell should be made up as follows:—

General Arrangement.

If a particularly low internal resistance is not required the glass vessel can have the H form used by Lord Rayleigh or Kahle's modification of it. The two legs of the vessel are provided with platinum leading-in wires melted into the glass at the lower ends (*see* Fig. 105). Two types will be described, one not being suitable for transporting without special care, the other intended to be transportable.

In the former type (Fig. 105) the negative pole consists of a cadmium amalgam—one part of cadmium to six parts of mercury is the mixture used at the Reichsanstalt. Over this is a layer of pulverised crystals of cadmium sulphate, to ensure this pole always being in contact with a concentrated solution. This layer of crystals also prevents the mercurous sulphate from coming into contact with the amalgam. The positive pole is formed of metallic mercury, over which is a layer of paste formed by the trituration of mercurous sulphate with metallic mercury, and a concentrated solution of cadmium sulphate in which are some crystals of this salt. The paste must not be too thin, but must form a stiff pulp. The remainder of the cell is filled with a concentrated solution of cadmium sulphate. The tube is closed first by a layer of paraffin which is poured in, and with a thin washer of cork upon the paraffin. Finally, the cell is sealed with good sealing-wax, which is not acted on by petroleum. Of course, the tops of each of the glass legs may be fused up in the blow-pipe instead.



REICHSANSTADT FORM of CADMIUM STANDARD CELL

Fig. 105.

In the portable type the negative pole is formed in the same way as above described, but the positive pole is of amalgamated platinum. In order to give this electrode a greater surface the platinum wire is either rolled in a spiral, or connected to a piece of platinum foil. The space taken up by the liquid in the first type is in this one filled entirely with the paste.

Special Instructions.

Amalgamation of the Platinum.—The amalgamation of the platinum is done electrolytically. The metal is first warmed with aqua regia in a sand bath until bubbles rise; then the cell is filled with a solution of mercury in nitric acid and the platinum is connected to the negative pole of a battery; another piece of platinum foil is used as anode. The current is allowed to flow until the platinum is covered regularly with mercury. The mercury must adhere well to the platinum.*

Cadmium Amalgam.—The E.M.F. of the cadmium cell is independent of the composition of the amalgam between the limits of 6 and 13 parts of mercury to one part of cadmium, and its value is that given at the end of the article. Cadmium dissolves easily in mercury when heated, forming a liquid amalgam which, if of the composition usually given it, viz. one part of cadmium to six of mercury, is solid at ordinary temperatures. To fill the one leg of the cell with the amalgam the simplest way is to place in it a small piece of the solid amalgam and heat it in the sand bath until it melts. The mercury used for making this amalgam must, of course, be pure. Commercial cadmium obtained from good factories is usually pure enough, and occasional small impurities have no effect on the cell.

Cadmium Sulphate.

The cadmium sulphate of commerce is also usually sufficiently pure, but it is not always thoroughly neutral. As free acid affects the E.M.F. of the cell, it must be neutralized. The acidity can be recognized by testing with litmus. Occasionally it is only the mother liquor surrounding the crystals that is acid, in which case it suffices to wash the salt with distilled water. Otherwise one must neutralize the acid by digesting a solution of the salt in cadmium hydroxide.† As the solution usually becomes somewhat basic by this means, and then on bringing it in contact with the mercurous sulphate the latter is precipitated, one digests it for some time with this salt before using it until no more precipitation of the latter occurs. The cadmium sulphate solution must not be warmed over 70°, for otherwise another hydrate is formed ($CdSO_4 + H_2O$, while under 70° the composition is $3CdSO_4 + 8H_2O$). The solubility of the cadmium sulphate changes very little with temperature, so that raising the temperature is of no use in producing a concentrated solution, and the finely-powdered salt must be shaken up with the solution so long as any of it is dissolved. If the solution is not concentrated the E.M.F. is too high. At ordinary temperatures 100 parts of water dissolve about 115 parts of the hydrate.

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* The platinum wire may also be amalgamated by heating to redness in a bunsen flame and plunging in a bath of pure mercury.

† Cadmium hydroxide may be precipitated by treating a solution of cadmium sulphate with a solution of caustic soda. The precipitate must be well washed.

Mercury.—The mercury for the positive pole can easily be obtained sufficiently pure by the usual methods; it must be free from any trace of a more positive metal.

Mercurous Sulphate (Hg_2SO_4).—This salt may be impure owing to oxides, basic salts, or free acid. Oxides are reduced by the rubbing of the paste with metallic mercury. Basic salts indicate their presence by a yellow coloration, and being insoluble are harmless. They can be transformed into neutral salts by treating the salt with very dilute sulphuric acid, and subsequently washing it with distilled water, only the washing must not be continued so long that they are again decomposed into basic salts. The last trace of acid in the paste is removed with finely divided metallic mercury. The treatment of a strongly acid salt follows from the foregoing. If the salt has a pale yellow colour, or if it shows a pale yellow coloration when put into water, it can be used without further treatment. If the salt has been washed in water it must be dried as well as possible (without heat), and, in making the paste, so much solid cadmium sulphate must be added that a saturated solution of the latter salt is also formed.

The E.M.F. of the cadmium cell is (for cadmium amalgams containing some 7 to 14 per cent. of cadmium)—

1·019 international volts at 20° C.,

if 1·433 international volts be taken as the E.M.F. of the Clark cell at 15° C. The effect of temperature is given in the formula—

$$E_t = E_{20} - 3{\cdot}8 \times 10^{-5}(t - 20) - 0{\cdot}065 \times 10^{-5}(t - 20)^2.$$

From experience with this cell since April, 1894, it has been found that it, as well as the Clark cell, is constant and reproducible within a ten-thousandth.

Further Remarks on the Cadmium Standard Cell.

In a paper communicated to the *Philosophical Magazine* (vol. xlviii., July, 1899, p. 152), Dr. John Henderson gives an account of a large series of investigations made by himself on this type of cell. The cell was made up in a single tube, and he states, amongst other things, that it is a matter of indifference whether the neutral or acid salts are employed in the construction of the cell, *provided acid is not added.* With regard to the temperature coefficient his investigations showed that the temperature coefficient is increased somewhat by the use of acid salts. Dr. Henderson concludes that as far as regards the fulfilment of the conditions necessary for a standard of E.M.F., the cadmium cell is distinctly superior to any modification of Clark cell.

No. 3.—The Manufacture of a 1-Ohm Coil.

Resistance coils for laboratory work are generally made of a length of metal wire wound on a convenient containing bobbin, the metal of the wire being preferably one having a very small or negligible temperature coefficient. Generally, the wire is made of German silver, an alloy composed of copper four parts, nickel two parts, and zinc one part. Its temperature coefficient is only one-ninth that of copper, being 0·0044 per degree centigrade, whilst its resistance is nearly thirteen times that of copper. To make a one-ohm coil, cut off about 45 cms. of silk-covered 28 S.W.G. German silver wire and bare the ends. Measure its resistance by the method given in experiment R8, using a standard one-ohm coil on the other side. It will be found that the resistance of the wire is somewhat above one ohm. Bare a little more wire until the resistance is just *slightly* over one ohm. Note that this resistance is that of the length of wire between the points where it leaves the binding screws. This is explained by the following figure:—

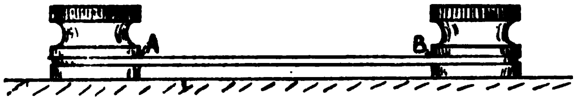


Fig. 106.

the resistance measured is that of the length of wire between the points A and B.

To note these points, bend the wire at right angles up against the terminals and take the wire out of the bridge.

Now obtain two 3″ pieces of stout bare copper wire, and carefully clean one end of each, and the bent ends of the length of German silver wire just made. Solder the ends very carefully to the copper wires, taking care to make a good clean electrical connection, and to solder just up to the bends, and finally wash the joints in water. Double the wire together at its middle point, and, inserting the copper terminal wire in hole in a bobbin top, carefully wind the double wire round the shank previously covered with a layer of tape or rubber insulation. Now attach thimble wire connectors to each of the copper wires, and connect up with short and thick wires to the bridge. If care has been exercised in soldering, the balance will be found to be the same as formerly, *i.e.* the resistance of the non-inductively wound coil is just *slightly* over one ohm. To adjust finally to exactly one ohm, cover the wire with a single wrapping of tape, taking great care in covering the terminal wires and leave only about 2 cms. of the doubled end exposed. Carefully unwrap the silk from off about half a centimetre of this end and clean the bare wire so that the coil appears as in the sketch—

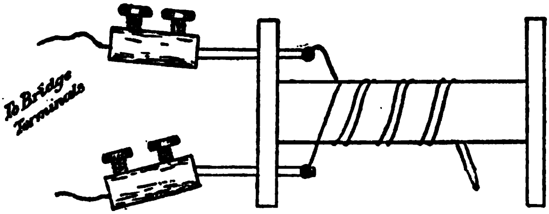


Fig. 107.

Take the soldering iron and momentarily apply the small globule of molten solder and resin flux to the bare end, which will leave a small globule adhering to the two wires, and thus short-circuiting a portion of the bend.

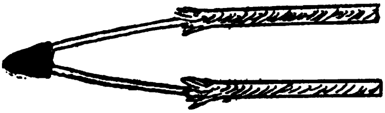


Fig. 108.

Extend this solder up the wire bend until the resistance is exactly one ohm. In doing this use a hot iron, apply it momentarily, and use a minimum amount of solder. By this method the resistance can be adjusted with great accuracy. To complete the coil, separate the remainder of the bared ends from each other by thin insulation, and finally insulate the whole end, bend down on the bobbin, and re-tape the whole. Test finally.

APPENDIX II

PHYSICAL TABLES

TABLE I.

USEFUL CONSTANTS, ETC.

1 gallon = 0·1604 cubic foot = 10 lbs. of fresh water at 62° F.
1 atmosphere = 14·7 lbs. per sq. inch = 760 mms. of mercury.
1 radian = 57·30 degrees. At Greenwich, $g = 981{\cdot}17$ cms. = 31·19 feet per sec. per sec.

Approximations.—If a and b are small quantities—

$$(1 \pm a)^m = 1 \pm ma \qquad (1 \pm a)^m(1 \pm b)^n = 1 \pm ma \pm nb.$$

Absorption of Light by Globes.—

Ordinary clear glass absorbs about ...	10%	of the light.
Light-ground „ „ „ ...	30%	„ „
Heavy-ground and tinted absorbs about	40%	„ „
Opal glass absorbs about	50%	„ „

Fuses. (Schwartz and James.) (d in cms. and fuses horizontal.)

Copper (tinned) ...	$C = 1768d^{1{\cdot}403}$,	for sizes 33 to 18 S.W.G.
Tin	$C = 2393d^{1{\cdot}32}$	„ 20 to 7 „
Aluminium ...	$C = 2188d^{1{\cdot}461}$	„ 42 to 22 „

Current for Incandescent Lamps.—

Supply, voltage.	Watts per candle-power.							
	4		3·5		3		2·5	
	16 c.-p.	25 c.-p.	16 c.-p.	25 c.-p.	16 c.-p.	25 p.-c.	16 c.-p.	25 c.-p.
100	0·64	1·0	0·56	0·87	0·48	0·75	0·40	0·62
110	0·58	0·91	0·51	0·80	0·44	0·68	0·36	0·57
200	0·32	0·50	0·28	0·44	0·24	0·37	0·20	0·31
220	0·29	0·45	0·25	0·40	0·22	0·34	0·18	0·28

TABLE I.—*continued.*

Attractive Force of an Electro-magnet $\left(P = \frac{B^2A}{8\pi}\text{ dynes}\right)$.

B per sq. cm.	1,000	2,000	4,000	6,000	8,000	10,000	15,000	20,000
Grms. per sq. cm.	40·6	162	650	1,460	2,600	4,060	9,150	16,230
Pounds per sq. in.	0·577	2·31	9·23	20·75	36·95	57·7	130	231

TABLE II.

FORMULÆ IN MENSURATION.

	Circumference.	Surface.	Volume.
Circle	$2\pi r = \pi d$	$\pi r^2 = \frac{\pi}{4}.d^2$	—
Cylinder ...	—	$2\pi rh + 2\pi r^2$	πr^2h
Sphere ...	—	$4\pi r^2 = 12{\cdot}57r^2$	$\frac{4}{3}\pi r^3 = 4{\cdot}189r^3$
Cone	—	$\pi r\sqrt{r^2 + h^2} + \pi r^2$	$\frac{\pi r^2h}{3} = 1{\cdot}047r^2h$

r = radius. d = diameter. h = height.

TABLE III.

CONVERSION FACTORS.

Length.

1 inch = 2·540 cms. 1 cm. = 0·3937 inch.
1 foot = 30·48 cms. 1 cm. = 0·03281 foot.
1 yard = 91·44 cms. 1 cm. = 0·010936 yard.
1 mile = 160935 cms. 1 cm. = $6{\cdot}2137 \times 10^{-6}$.

Area.

1 sq. in. = 6·4517 sq. cms. 1 sq. cm. = 0·1550 sq. in.
1 sq. ft. = 929·04 sq. cms. 1 sq. cm. = 0·0010764 sq. ft.
1 sq. yd. = 8361·35 sq. cms. 1 sq. cm. = 0·0001196 sq. yd.
1 sq. mile = $2{\cdot}59 \times 10^{10}$ sq. cms. 1 sq. cm. = $3{\cdot}861 \times 10^{-11}$ sq. mile.

TABLE III.—*continued.*

Volume.

1 cub. in. = 16·388 cub. cms. 1 cub. cm. = 0·06102 cub. in.
1 cub. ft. = 28,317 cub. cms. 1 cub. cm. = 3·5314 × 10^{-5} cub. ft.
1 cub. yd. = 764,564 cub. cms. 1 cub. cm. = 1·308 × 10^{-6} cub. yd.
1 pint = 567·63 cub. cms. 1 cub. cm. = 0·001762 pint.

Mass.

1 grain = 0·0647990 grms. 1 grm. = 15·432 grain.
1 ounce (avr.) = 28·3495 grms. 1 grm. = 0·035274 ounce (avr.).
1 pound = 453·59 grms 1 grm. = 0·0022046 pound.
1 ton = 1·01605 × 10^{6} grms. 1 grm. = 9·8421 × 10^{-7} ton.

Velocity.

1 ft. per sec. = 30·48 cm. per sec. 1 cm. per sec. = 0·03281 ft. per sec.
1 mile per hr. = 44·704 cm. per sec. 1 cm. per see. = 0·02237 mile per hr.
1 kilo. per hr. = 27·778 cm. per sec. 1 cm. per sec. = 0·036 kilo. per hr.

Force.

1 poundal = grms. = 13825 dynes.
1 pound = 453·59 grms. = 4·45 × 10^{8} dynes.
1 grain = 0·064799 grms. = 63·6 dynes.
1 kilogramme = 1000 grms. = 9·81 × 10^{5} dynes.

Work and Energy.

1 ft.-pound = 13823 grm. cms. = 1·3560 × 10^{7} ergs.
1 ft.-poundal = = 4·2140 × 10^{5} ergs.
1 kilogrammetre = 10^{5} grm. cms. = 9·81 × 10^{7} ergs.
1 joule = = 10^{7} ergs.

Rate of Work.

1 horse-power = 7·604 × 10^{6} grm. cms. per sec. = 7·46 × 10^{9} ergs per sec.
1 force-de-cheval = 7·5 × 10^{6} grm. cms. per sec. = 7·36 × 10^{9} ergs per sec.
1 kilowatt = = 10^{10} ergs per sec.
1 watt = = 10^{7} ergs per sec.

Mechanical Equivalent of Heat.

(For water at 7·5° C. or 45·5° F.)

1 grm. through 1° C. = 4·281 × 10^{4} grm. cms. = 4·2 × 10^{7} ergs.
1 lb. through 1° C. = 1·942 × 10^{7} grm. cms. = 1·905 × 10^{10} ergs.
1 lb. through 1° F. = 1·079 × 10^{7} grm. cms. = 1·058 × 10^{10} ergs.

TABLE IV.

SPECIFIC GRAVITIES AND SPECIFIC HEATS.

(Everett, Gray, and others.)

Substance.	Specific gravity.	Specific heat.
Aluminium	2·6 to 2·8	0·2122
Bismuth	9·7 „ 9·9	0·0298
Brass (4 Cu, 1 Sn)	8·44 „ 8·7	0·0858
Bronze	8·74 „ 8·89	0·090
Carbon (gas)	1·88	0·16
Copper (sheet)	8·8 to 8·89	0·0933
„ (wire)	8·3 „ 8·89	0·0933
German silver	8·3 „ 8·45	—
Gold	19·26 „ 19·34	0·0316
Iron (gray cast)	7·03 „ 7·13	0·1124
„ (white cast)	7·58 „ 7·73	0·1124
„ (wrought)	7·8 „ 7·9	0·1124
Steel	7·8 „ 7·9	0·116
Lead	11·34 „ 11·36	0·0315
Mercury (at 0° C.)	13·596	0·0335
Manganin	8·7	—
Nickel	8·3 to 8·9	0·1092
Platinum	21·2 „ 21·7	0·0323
Silver	10·4 „ 10·57	0·0559
Tin	7·29 „ 7·3	0·0559
Zinc	7·04 „ 7·18	0·0935
Glass (common)	2·4 „ 2·8	0·198
Paraffin (solid)	0·87 „ 0·91	—
Ebonite	1·15	—
Gutta percha	0·97 to 0·98	—
Petroleum	0·878	0·495
Sulphuric acid	1·85	0·332
Nitric acid	1·56	$+ 10H_2O$ 0·768
Hydrochloric acid	1·27	$+ 10H_2O$ 0·749

TABLE V.

Specific Resistances and Temperature Coefficients of Pure Metals and Alloys.

(Professors J. A. Fleming and J. Dewar.)

Pure metals.	ρ Micr-ohms.	Temp. coeff. α.	Alloys.	ρ Micr-ohms.	Temp. coeff. α.
Platinum	10·917	+0·003669	Platinum-silver ...	31·582	+0·000243
Gold ...	2·197	0·003770	„ -iridium	30·896	0·000822
Silver ...	1·468	0·004000	„ -rhodium	21·142	0·00143
Copper ...	1·561	0·004280	Manganese steel ...	67·148	0·00127
Aluminium	2·665	0·004350	Nickel steel ...	29·452	0·00201
Iron ...	9·065	0·006250	German silver ...	29·982	0·000273
Nickel ...	12·323	0·006220	Platinoid... ...	41·731	0·000310
Tin ...	13·048	0·004400	Manganin ...	46·678	0·00000
Magnesium	4·355	0·003810	Aluminium bronze	12·300	0·0010
Zinc ...	5·751	0·004060	Brass	7·2	
Cadmium	10·023	0·004190			
Lead ...	20·380	0·004110			
Mercury ...	94·070	0·000720			

The *specific resistances* in microhms per c.c. are taken at 0° C., and the *mean* values are given for α between the limits of 0° C. and 100° C.

TABLE VI.

SPECIFIC RESISTANCE OF ELECTROLYTES IN OHMS PER CUBIC CM.

(Approximate values.)

Substance.	Specific resistance.	Temperature.
Sulphate of copper, saturated	29·30	10° C.
Sulphate of zinc "	33·70	"
" " minimum	28·3	"
" " 25 per cent. solution of *anhydrous* salt	21·11	18° C.
Sulphate of potash, saturated	16·6	10° C.
Sodium chloride "	4·70	18° C.
Bichromate of potash, saturated	29·60	10° C.
Nitric acid, $\Delta = 1·36$	1·40	—
Sulphuric acid, 5 per cent., $\Delta = 1·033$ ...	4·926	18°C.
" " 10 " $\Delta = 1·067$ ...	2·623	"
" " 15 " $\Delta = 1·104$ ...	1·891	"
" " 20 " $\Delta = 1·141$ ...	1·574	"
" " 30 " $\Delta = 1·221$ ...	1·391	"
" " 40 " $\Delta = 1·306$ ...	1·511	"
Copper sulphate, 5 per cent., $\Delta = 1·032$ ...	53·3	"
" " 10 " $\Delta = 1·065$ ...	31·4	"
" " 15 " $\Delta = 1·0993$ ...	23·9	"
" " 17·5 " — ...	21·9	"
Caustic soda, 5 per cent., $\Delta = 1·058$ ...	5·12	"
" " 10 " $\Delta = 1·115$ ...	3·22	"
" " 15 " $\Delta = 1·170$ ...	2·90	"
" " 20 " $\Delta = 1·225$ ...	3·08	"
" " 30 " $\Delta = 1·332$ ...	4·99	"
" " 40 " $\Delta = 1·437$ ...	8·70	"

Δ = specific gravity.

TABLE VII.

ELECTRO-CHEMICAL EQUIVALENTS IN GRAMMES PER COULOMB.

Metal.	Atomic weight.	Chemical equivalent $= \frac{\text{at. wt.}}{\text{valency}}$	Electro-chemical equivalent, grammes per coulomb.	Grammes deposited per amp. hour.
Aluminium ...	27	9	0·00009317	0·3354
Copper (cuprous)	63·1	63·1	0·00065735	2·3665
„ (cupric) ...	63·1	31·6	0·00032867	1·1832
Gold	196·7	65·6	0·00067806	2·4410
Iron (ferrous) ...	56	28	0·00028986	1·0435
Lead	206·4	103·2	0·0010714	3·8571
Nickel	58·6	29·3	0·00030538	1·0994
Silver	108	108	0·0011180	4·0249
Tin (stannous) ...	117·8	58·9	0·00061077	2·1988
Zinc	65	32·5	0·00033644	1·2112
Hydrogen... ...	1	1	0·000010352*	0·03738

* The difference between the value given here and that given on p. 46 is explained by the fact that fresh determinations of z for H are constantly being made. A recent determination gives the value at 0·00001044, to use which the above values would have to be increased by about 0·9%.

TABLE VIII.

PROPERTIES OF PRIMARY CELLS.

Name of cell.	Electrodes.	Solutions.	E.M.F.	Approx. internal resistance.
				ohms
Daniell ...	Copper and zinc	The zinc is immersed in a solution of zinc sulphate, and the copper in a solution of copper sulphate	Depends upon the densities of the solutions, it varies from 1·07 to 1·14 volts	1 to 10
Leclanché	Carbon and zinc	The carbon is packed in a porous pot with peroxide of manganese and broken gas carbon. The zinc is immersed in solution of sal ammoniac	About 1·47 volts; but is quickly reduced if used to send a strong current	1·5 to 3·5
Clark ... (standard)	Pure mercury and pure zinc	The mercury is covered with a paste of mercurous sulphate and a saturated solution of zinc sulphate, in which is placed the rod of zinc	1·434 at 15° C. at any temperature $t°$ C., it is $1{\cdot}434[1-0{\cdot}0008(t°-15°)]$	—
Bunsen ...	Carbon and zinc	The carbon in nitric acid, and the zinc in dilute sulphuric acid	About 1·9 volts	0·15 to 2
Bichromate	Carbon and zinc	The best solution is 1 lb. of potassium-bichromate, 2 lbs. strong sulphuric acid, specific gravity 1·836, and 12 lbs. water, in which both electrodes are immersed, the zinc being withdrawn when the cell is not in use	About 2 volts; but is quickly reduced if employed to send a strong current	1 to 2
Grove ...	Platinum and zinc	The platinum is immersed in a strong nitric acid, and the zinc in dilute sulphuric acid	About 1·93 volts	0·15 to 4

TABLE IX.

Relation between Practical and C.G.S. (absolute) Units.

	Practical unit.	Absolute C.G.S. units.		Dimensions.	
		Electro-magnetic.	Electrostatic.	Electro-static.	Electro-magnetic.
Quantity	Coulomb	10^{-1}	$v \times 10^{-1} = 3 \times 10^{9}$	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$	$M^{\frac{1}{2}}L^{\frac{1}{2}}$
Current	Ampère	10^{-1}	$v \times 10^{-1} = 3 \times 10^{9}$	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}$	$M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$
Potential	Volt	10^{8}	$10^{8} \div v = \frac{1}{3} \times 10^{-2}$	$M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}$
Resistance	Ohm	10^{9}	$\frac{1}{v^2} \times 10^{9} = \frac{1}{9} \times 10^{-11}$	$L^{-1}T$	LT^{-1}
Capacity	Farad	10^{-9}	$v^2 \times 10^{-9} = 9 \times 10^{11}$	L	$L^{-1}T^{2}$
Self induction	Secohm	10^{9}	—	—	L
Mutual induction	Secohm	10^{9}	—	—	L
Power	Watt	10^{7}	—	—	$ML^{2}T^{-3}$
Work	Joule	10^{7}	—	—	$ML^{2}T^{-2}$
Induction	Maxwell	10^{8}	$v = 3 \times 10^{10}$	—	$M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}$

v = velocity of light = 3×10^{10} cms. per second.

TABLE X.

VARIATION OF E.M.F. OF CLARK STANDARD AND OF CARHART-CLARK STANDARD CELL WITH TEMPERATURE.

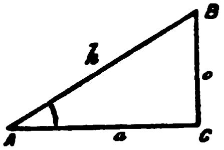
Temperature °C.	**E.M.F. in legal volts.**	
	Clark.	**Carhart-Clark.**
4	1·4461	1·4395
5	1·4450	1·4390
6	1·4439	1·4385
7	1·4428	1·4380
8	1·4417	1·4375
9	1·4406	1·4370
10	1·4395	1·4365
11	1·4384	1·4360
12	1·4373	1·4355
13	1·4362	1·4350
14	1·4351	1·4345
15	1·4340	1·4340
16	1·4329	1·4335
17	1·4318	1·4330
18	1·4307	1·4325
19	1·4296	1·4320
20	1·4285	1·4315
21	1 4274	1·4310
22	1·4263	1·4305
23	1·4252	1·4300
24	1·4241	1·4295
25	1·4230	1·4290
26	1·4219	1·4285
27	1·4208	1·4280
28	1·4197	1·4275
29	1·4186	1·4270
30	1·4175	1·4265

TABLE XI.

TRIGONOMETRICAL RATIOS.

If A be one acute angle in the right-angled triangle ABC—

a = side adjacent to angle A
o = side opposite to angle A
h = hypotenuse



Ratio.	Values.				
	0°	30°	45°	60°	90°
$\sin A = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{o}{h}$	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1
$\cos A = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{a}{h}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
$\tan A = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{o}{a}$	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞
$\cot A = \frac{\text{adjacent side}}{\text{opposite side}} = \frac{a}{o}$	∞	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0
$\sec A = \frac{\text{hypotenuse}}{\text{adjacent side}} = \frac{h}{a}$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞
$\operatorname{cosec} A = \frac{\text{hypotenuse}}{\text{opposite side}} = \frac{h}{o}$	∞	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1

TABLE XII.—LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						4	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	37
11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969					3	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	7	10	12	16	19	22	25	29
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	28
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	5	8	11	14	16	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	15	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	19	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	16	19	21
						2672	2695	2718	2742	2765	2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

The copyright of that portion of the above table which gives the logarithms of numbers from 1000 to 2000 is the property of Messrs. Macmillan and Company, Limited, who, however, have authorized the use of the form in any reprint published for educational purposes.

TABLE XII. (*continued*)—LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8098	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9756	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

TABLE XII.—ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

TABLE XII. (*continued*).—ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

TABLE XIII.—Trigonometrical Tables.

Angle.		Chord.	Sine.	Tangent.	Co-tangent.	Cosine.			
Degrees.	Radians.								
0°	0	0	0	0	∞	1	1·414	1·5708	90°
1	·0175	·017	·0175	·0175	57·2900	·9998	1·402	1·5533	89
2	·0349	·035	·0349	·0349	28·6363	·9994	1·389	1·5359	88
3	·0524	·052	·0523	·0524	19·0811	·9986	1·377	1·5184	87
4	·0698	·070	·0698	·0699	14·3007	·9976	1·364	1·5010	86
5	·0873	·087	·0872	·0875	11·4301	·9962	1·351	1·4835	85
6	·1047	·105	·1045	·1051	9·5144	·9945	1·338	1·4661	84
7	·1222	·122	·1219	·1228	8·1443	·9925	1·325	1·4486	83
8	·1396	·140	·1392	·1405	7·1154	·9903	1·312	1·4312	82
9	·1571	·157	·1564	·1584	6·3138	·9877	1·299	1·4137	81
10	·1745	·174	·1736	·1763	5·6713	·9848	1·286	1·3963	80
11	·1920	·192	·1908	·1944	5·1446	·9816	1·272	1·3788	79
12	·2094	·209	·2079	·2126	4·7046	·9781	1·259	1·3614	78
13	·2269	·226	·2250	·2309	4·3315	·9744	1·245	1·3439	77
14	·2443	·244	·2419	·2493	4·0108	·9703	1·231	1·3265	76
15	·2618	·261	·2588	·2679	3·7321	·9659	1·218	1·3090	75
16	·2793	·278	·2756	·2867	3·4874	·9613	1·204	1·2915	74
17	·2967	·296	·2924	·3057	3·2709	·9563	1·190	1·2741	73
18	·3142	·313	·3090	·3249	3·0777	·9511	1·176	1·2566	72
19	·3316	·330	·3256	·3443	2·9042	·9455	1·161	1·2392	71
20	·3491	·347	·3420	·3640	2·7475	·9397	1·147	1·2217	70
21	·3665	·364	·3584	·3839	2·6051	·9336	1·133	1·2043	69
22	·3840	·382	·3746	·4040	2·4751	·9272	1·118	1·1868	68
23	·4014	·399	·3907	·4245	2·3559	·9205	1·104	1·1694	67
24	·4189	·416	·4067	·4452	2·2460	·9135	1·089	1·1519	66
25	·4363	·433	·4226	·4663	2·1445	·9063	1·075	1·1345	65
26	·4538	·450	·4384	·4877	2·0503	·8988	1·060	1·1170	64
27	·4712	·467	·4540	·5095	1·9626	·8910	1·045	1·0996	63
28	·4887	·484	·4695	·5317	1·8807	·8829	1·030	1·0821	62
29	·5061	·501	·4848	·5543	1·8040	·8746	1·015	1·0647	61
30	·5236	·518	·5000	·5774	1·7321	·8660	1·000	1·0472	60
31	·5411	·534	·5150	·6009	1·6643	·8572	·985	1·0297	59
32	·5585	·551	·5299	·6249	1·6003	·8480	·970	1·0123	58
33	·5760	·568	·5446	·6494	1·5399	·8387	·954	·9948	57
34	·5934	·585	·5592	·6745	1·4826	·8290	·939	·9774	56
35	·6109	·601	·5736	·7002	1·4281	·8192	·923	·9599	55
36	·6283	·618	·5878	·7265	1·3764	·8090	·908	·9425	54
37	·6458	·635	·6018	·7536	1·3270	·7986	·892	·9250	53
38	·6632	·651	·6157	·7813	1·2799	·7880	·877	·9076	52
39	·6807	·668	·6293	·8098	1·2349	·7771	·861	·8901	51
40	·6981	·684	·6428	·8391	1·1918	·7660	·845	·8727	50
41	·7156	·700	·6561	·8693	1·1504	·7547	·829	·8552	49
42	·7330	·717	·6691	·9004	1·1106	·7431	·813	·8378	48
43	·7505	·733	·6820	·9325	1·0724	·7314	·797	·8203	47
44	·7679	·749	·6947	·9657	1·0355	·7193	·781	·8029	46
45°	·7854	·765	·7071	1·0000	1·0000	·7071	·765	·7854	45°
			Cosine	Co-tangent	Tangent	Sine	Chord	Radians	Degrees
								Angle	

TABLE XIV.

STANDARD WIRE-GAUGE TABLE.

Resistance, conductivity, and weight of hard-drawn pure copper wires at 15° C. Calculated by taking the specific resistance of copper at 0° C. to be $1{,}620 \times 10^{-9}$ Board of Trade ohm, and the conductivity at temperature $t°$ C. $= 1 - 0·0038701t + 0·000009009t^2$.

No. of B.T. wire gauge.	Diameter.		Area of cross-section.		Weight (density = 8·95).		Conductivity.		Resistance.	
	Ins.	Cms.	Sq. ins.	Sq. cms.	Lbs. per yard.	Grammes per metre.	Yards per B.T. ohm.	Metres per B.T. ohm.	B.T. ohms per yard.	B.T. ohms per metre.
0000000	0·500	1·270	0·1964	1·2668	2·285	1134	8073	7382	0·000124	0·000135
000000	0·464	1·179	0·1691	1·0909	1·970	976·3	6952	6357	0·000144	0·000157
00000	0·432	1·097	0·1466	0·9456	1·706	846·3	6026	5510	0·000166	0·000181
0000	0·400	1·016	0·1257	0·8107	1·463	725·6	5166	4724	0·000194	0·000212
000	0·372	0·945	0·1087	0·7012	1·265	627·6	4468	4086	0·000224	0·000245
00	0·348	0·884	0·0951	0·6136	1·107	549·6	3910	3576	0·000256	0·000280
0	0·324	0·823	0·0824	0·5319	0·960	476·1	3390	3099	0·000295	0·000323
1	0·300	0·762	0·0707	0·4560	0·823	408·1	2906	2657	0·000344	0·000376
2	0·276	0·701	0·0598	0·3860	0·696	345·4	2460	2249	0·000407	0·000445
3	0·252	0·640	0·0499	0·3218	0·581	288·0	2051	1875	0·000488	0·000553
4	0·232	0·589	0·0423	0·2727	0·492	244·1	1738	1589	0·000575	0·000629
5	0·212	0·538	0·0353	0·2277	0·411	203·8	1452	1327	0·000689	0·000754

6	0·192	0·488	0·0290	0·1868	0·337	166·8	1190	1089	0·000840	0·000919
7	0·176	0·447	0·0243	0·1570	0·283	140·5	1000	914	0·00100	0·00109
8	0·160	0·406	0·0201	0·1297	0·234	116·1	827	756	0·00121	0·00132
9	0·144	0·366	0·0163	0·1051	0·190	94·0	670	612	0·00149	0·00163
10	0·128	0·335	0·0129	0·0830	0·150	74·3	529	484	0·00189	0·00207
11	0·116	0·295	0·0106	0·0682	0·123	61	435	397	0·00230	0·00252
12	0·104	0·264	0·00849	0·0548	0·0989	49	349	319	0·00286	0·00313
13	0·092	0·234	0·00665	0·0429	0·0774	38·4	273	250	0·00366	0·00400
14	0·080	0·203	0·00503	0·0324	0·0585	29	207	189	0·00484	0·00529
15	0·072	0·183	0·00407	0·0263	0·0474	23·5	167	153	0·00597	0·00653
16	0·064	0·163	0·00322	0·0208	0·0374	18·6	132	121	0·00756	0·00827
17	0·056	0·142	0·00246	0·0159	0·0287	14·2	101	92·6	0·00988	0·0108
18	0·048	0·122	0·00181	0·0117	0·0211	10·4	74·4	68	0·0134	0·0147
19	0·040	0·102	0·00126	0·00811	0·0146	7·26	51·7	47·2	0·0194	0·0212
20	0·036	0·0914	0·00102	0·00657	0·0118	5·88	41·9	38·3	0·0239	0·0261
21	0·032	0·0813	0·000804	0·00519	0·00936	4·64	33·1	30·2	0·0302	0·0331
22	0·028	0·0711	0·000616	0·00397	0·00717	3·56	25·3	23·1	0·0395	0·0432
23	0·024	0·0610	0·000452	0·00292	0·00526	2·61	18·6	17	0·0538	0·0588
24	0·022	0·0559	0·000380	0·00245	0·00443	2·19	15·6	14·3	0·0640	0·0700
25	0·020	0·0508	0·000314	0·00203	0·00366	1·80	12·9	11·8	0·0774	0·0847
26	0·018	0·0457	0·000254	0·00164	0·00296	1·47	10·5	9·59	0·0956	0·105
27	0·0164	0·0417	0·000211	0·00136	0·00246	1·22	8·68	7·94	0·115	0·126
28	0·0148	0·0376	0·000172	0·00111	0·00200	0·893	7·07	6·47	0·141	0·155
29	0·0136	0·0345	0·000145	0·000937	0·00169	0·839	5·97	5·46	0·167	0·183
30	0·0124	0·0315	0·000121	0·000779	0·00141	0·697	4·96	4·54	0·201	0·220

TABLE XIV.—(*continued*).

No. of B.T. wire gauge.	Diameter.		Area of cross-section.		Weight (density = 8·95).		Conductivity.		Resistance.	
	Ins.	Cms.	Sq. ins.	Sq. cms.	Lbs. per yard.	Grammes per metre.	Yards per B.T. ohm.	Metres per B.T. ohm.	B.T. ohms per yard.	B.T. ohms per metre.
31	0·0116	0·0295	0·000106	0·000682	0·00123	0·610	4·35	3·97	0·230	0·252
32	0·0108	0·0274	0·0000916	0·000591	0·00107	0·529	3·77	3·44	0·266	0·290
33	0·0100	0·0254	0·0000785	0·000507	0·000914	0·453	3·23	2·95	0·310	0·339
34	0·0092	0·0234	0·0000665	0·000429	0·000774	0·384	2·73	2·50	0·366	0·400
35	0·0084	0·0213	0·0000554	0·000358	0·000645	0·320	2·28	2·08	0·439	0·480
36	0·0076	0·0193	0·0000454	0·000293	0·000548	0·262	1·87	1·71	0·536	0·586
37	0·0068	0·0173	0·0000363	0·000234	0·000423	0·210	1·49	1·37	0·670	0·732
38	0·0060	0·0152	0·0000283	0·000182	0·000329	0·163	1·16	1·06	0·860	0·941
39	0·0052	0·0132	0·0000212	0·000137	0·000247	0·123	0·873	0·798	1·15	1·25
40	0·0048	0·0122	0·0000181	0·000117	0·000211	0·104	0·744	0·680	1·34	1·47
41	0·0044	0·0112	0·0000152	0·0000981	0·000177	0·0878	0·625	0·572	1·60	1·75
42	0·0040	0·0102	0·0000126	0·0000811	0·000146	0·0726	0·517	0·473	1·94	2·12
43	0·0036	0·00914	0·0000102	0·0000657	0·000118	0·0588	0·419	0·383	2·39	2·61
44	0·0032	0·00813	0·00000804	0·0000519	0·0000936	0·0464	0·331	0·302	3·03	3·31
45	0·0028	0·00712	0·00000616	0·0000397	0·0000717	0·0356	0·253	0·232	3·95	4·32
46	0·0024	0·00610	0·00000452	0·0000292	0·0000527	0·0261	0·186	0·170	5·38	5·88
47	0·0020	0·00508	0·00000314	0·0000203	0·0000366	0·0181	0·129	0·118	7·74	8·47
48	0·0016	0·00406	0·00000201	0·0000130	0·0000234	0·0116	0·0827	0·0756	12·1	13·2
49	0·0012	0·00305	0·00000113	0·00000730	0·0000132	0·00653	0·0465	0·0425	21·5	23·5
50	0·0010	0·00254	0·000000785	0·00000507	0·00000914	0·00453	0·0323	0·0295	31	33·9

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